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BODY MEASUREMENTS AS RELATED TO LIVE WEIGHT IN SWINE

A. González Chapel[1]

Introduction

Body measurements have a certain value in swine breeding and selection. Their usefulness arises from their relationship to the live weight of pigs. Winters (6),[2] stated that the weight of hogs can be calculated to a remarkable degree of accuracy by measurements.

Three body measurements, length from poll to tail head, heart girth, and flank girth, were compared with weight in a number of boars and barrows of imported, native, and crossbred pigs reared in Puerto Rico, which entered individual feeding trials.

The main objective of the study was to ascertain which measurement or measurements at weaning, with or without weight information, would be useful as an aid to selection for weight at 168 days of age. Although some work on the subject had been already reported in the United States, some differences were anticipated in this study because the pigs were reared under tropical conditions.

Winters (6), reported a formula for calculating weight at any age by measurements in inches: Heart girth × heart girth × length ÷ 400 = weight in pounds. He stated that the formula is more accurate when used on hogs under 300 pounds than on heavier animals. He also presented a comparative table of the length, heart girth, and flank girth of boars and barrows of the Poland China and Minnesota No. 1 breeds at 24 weeks of age, and noted important sex differences in the measurements.

[1] Associate Animal Husbandman, Lajas Substation and Seed Farm, Agricultural Experiment Station, University of Puerto Rico, Lajas, P. R.

The following persons contributed in one way or another to the progress of this study: Dr. R. E. Comstock, now of the North Carolina Institute of Statistics, initiated the work and directed the first feeding trial. Dr. W. W. Green, now of the University of Maryland, directed the second feeding trial and made suggestions for the better conduct of the work. Mr. Tomás Quiñones, who died in November 1948, was Swine Herdsman at La Plata, during the period covered in this study. His unceasing dedication to his work made possible the collection of most of the data presented here.

[2] Numerals in parentheses refer to Literature Cited, page 100-01.

Godbey et al (3), reported the coefficients of correlation of some measurements and weight at birth, and at 56, 112, and 168 days of age for 100 Berkshire barrows. They also reported the standard deviations and coefficients of variation of these measurements and weights.

González Chapel and Cabrera (4), showed that weaning weight could be used to some extent to predict the weight at 154 days of age of practically the same lot of pigs used in the present study.

Increasing the accuracy of the selection at an early age of pigs for breeding or subsequent rearing would, of course, reduce the cost of the selection and increase the efficiency of the herd management.

Procedure

The study reported here was conducted at the La Plata Animal Production Sub-station of the Agricultural Experiment Station, University of Puerto Rico, from March 1946 to August 1948. Four individual feeding trials were made during that period.

The following breeds and crossbreds were included in one or more of the different trials:

	Boars	*Barrows*		*Boars*	*Barrows*
Duroc Jersey	9	9	Landrace Large Black x Native	13	13
Natives	14	14	Tamworth x Duroc	4	4
Landrace Large Black x Duroc	11	11	Tamworth x Native	4	4
Duroc x Native	11	11			

A total of 132 pigs, 66 boars and 66 barrows, were considered. The source of the stock used was reported earlier (4).

The measurements were taken in inches and the weight in pounds by the same individual throughout the experiment.

The data were collected at weaning, (56 days), and at 84, 112, 140, and 168 days. Three measurements were made on each individual at each age and an average of the three was taken as representative of the measurement.

The same feed concentrate was given to the hogs and the same men took care of them throughout the trials.

The methods of multiple regression and analyses of variance outlined by Snedecor (5), were used in the study of the relationships. Capó's (1) design for the solution of normal equations was also used in the analysis of the data.

Experimental Findings

Measurements as related to breed and sex

Winters and Green (7), indicated that different strains of swine change body proportions at different ages. Winters (6), stated that swine change

form as they grow and, as weight increases, barrows and boars follow different paths of development in conformation.

The three measurements considered in this study differed significantly from each other at practically all ages in each of the four trials. Table 1 shows the average length, heart girth, and flank girth of all pigs in each of the trials, regardless of breed or sex.

Pigs of all breeds and both sexes had greater length than girth and greater flank girth than heart girth. From weaning to 168 days of age the

TABLE 1.—*Average measurements of length, heart girth, and flank girth of the pigs at different ages*

Age (days)	Measurements of—											
	Length in—				Heart girth in—				Flank girth in—			
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 1	Trial 2	Trial 3	Trial 4	Trial 1	Trial 2	Trial 3	Trial 4
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
56	26.26	25.49	24.97	23.66	23.60	22.03	21.43	22.34	24.72	23.70	22.48	23.14
84	32.52	32.70	31.25	31.25	28.32	26.87	25.28	27.23	30.70	29.06	26.11	29.73
112	37.65	37.94	37.85	37.45	33.02	31.21	29.60	32.20	34.84	33.36	30.35	33.36
140	42.99	42.72	42.52	43.29	36.82	36.10	33.62	36.84	38.81	38.00	34.58	38.59
168	45.56	46.27	45.88	45.96	40.69	40.01	37.26	40.26	42.56	41.45	38.27	41.93

TABLE 2.—*Average length, heart-girth, and flank-girth measurements of boars and barrows used in these experiments, at different ages*

Age (days)	Boars			Barrows		
	Length	Heart girth	Flank girth	Length	Heart girth	Flank girth
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
56	25.63	22.53	23.72	24.65	22.01	23.14
84	32.50	26.92	28.93	31.32	26.59	28.28
112	38.39	31.69	33.15	37.11	30.89	32.26
140	43.61	35.91	37.41	42.07	35.42	37.14
168	46.60	39.67	40.95	45.25	38.99	40.62

pigs gained an average of 20.82 in. in length; 17.54 in. in flank girth, and 17.20 in. in heart girth. Most of the differences in measurements were probably caused by the initial difference at weaning, but this initial difference was observed in each of the four trials.

Table 2 contains a summary of the three measurements for the boars and the barrows, regardless of breed or trials.

The apparent over-all tendency was for the boars to have greater length and girth than the barrows at practically all ages; but statistical significance was found only in respect to length at the later ages in trials 1 and 2, and at

the earlier ages in trial 4. Some of these differences may have been produced by the initial difference at weaning.

The probable reason for the initial difference was explained in a previous report (4). The pigs selected to be barrows were castrated approximately 1 week before weaning and were chosen at random from the males selected for the individual feeding trials. The disturbance caused by castration, though temporary, may be partly responsible for the difference at weaning between the boars and the barrows.

Winters (6) reported that in a study of the effect of sex on the development of the pig at the Minnesota Agricultural Experiment Station, the boars and barrows followed different growth patterns. The boars gained weight faster for a time, but the barrows passed them later at a different time for each line of breeding. He further concluded that the effect of sex should be taken into account in a careful appraisal of data on growth and body form.

The average length of the different breeds at each of the trials is given in table 3.

The only statistically significant differences in length at 168 days of age were observed in trial 1 where the Landrace Large Black x Native proved to be longer than the Duroc and the Duroc than the Native. In trial 2 there were breed differences only at 112 days of age, the Landrace crossbreds being longer than the Native and Duroc x Native; the significance of the differences, however, disappeared at later ages. At 56 and at 112 days of age, in trial 3, the Durocs were significantly longer than the other breeds and the Tamworth x Native was the shortest. However, the significance of these differences disappeared at later ages. In trial 4 there were breed differences at 84 days of age; the Duroc crossbreds were longer than the Native and Landrace Large Black x Native, but the significance on these differences also disappeared at later ages.

The average heart girth of the different breeds at each of the trials is shown in table 4.

Significant differences were found in trial 1 at 140 and 168 days of age; the Durocs and Landrace Large Black x Native had greater heart girth than the Native. In trial 2 there were breed differences at 56 and 112 days of age; the Duroc x Native started with less heart girth than the other breeds but gained in the measurement until the significance of the differences disappeared at later ages. Significant differences were found at all ages in trial 3; from 56 to 140 days the Tamworth x Native was inferior to all other breeds in heart girth; the Durocs started with the best heart girth but at 140 and 168 days of age the crossbreds, with the exception of the Tamworth x Native, were better than the Durocs in this measurement. The only significant difference found in trial 4 was at 84 days of age when the Landrace

TABLE 3.—*Average length of the different breeds of swine used, at different ages*

Breed	Trial No.—			
	1	2	3	4
At 56 days of age				
	Inches	*Inches*	*Inches*	*Inches*
Duroc Jersey	25.64	—	26.66	—
Landrace Large Black x Duroc	—	26.05	24.35	24.65
Duroc x Native	—	24.51	24.73	24.00
Tamworth x Duroc	—	—	25.66	—
Native	26.56	25.51	—	22.47
Landrace Large Black x Native	26.78	26.23	25.16	23.22
Tamworth x Native	—	—	23.72	—
At 84 days of age				
Duroc Jersey	31.69	—	32.81	—
Landrace Large Black x Duroc	—	32.47	29.81	32.00
Duroc x Native	—	32.27	32.69	32.58
Tamworth x Duroc	—	—	31.56	—
Native	32.80	32.58	—	29.22
Landrace Large Black x Native	33.36	33.70	33.22	31.42
Tamworth x Native	—	—	28.34	—
At 112 days of age				
Duroc Jersey	37.32	—	42.44	—
Landrace Large Black x Duroc	—	39.83	36.50	38.85
Duroc x Native	—	36.31	38.60	36.89
Tamworth x Duroc	—	—	36.89	—
Native	37.89	37.23	—	36.00
Landrace Large Black x Native	37.81	39.42	37.30	37.14
Tamworth x Native	—	—	36.39	—
At 140 days of age				
Duroc Jersey	42.83	—	44.72	—
Landrace Large Black x Duroc	—	43.22	41.39	45.12
Duroc x Native	—	42.08	43.10	43.25
Tamworth x Duroc	—	—	42.39	—
Native	42.83	42.13	—	41.58
Landrace Large Black x Native	43.50	44.08	42.36	42.03
Tamworth x Native	—	—	40.75	—
At 168 days of age				
Duroc Jersey	45.88	—	47.58	—
Landrace Large Black x Duroc	—	47.03	44.52	48.00
Duroc x Native	—	46.41	46.19	46.03
Tamworth x Duroc	—	—	45.27	—
Native	44.10	45.18	—	45.00
Landrace Large Black x Native	46.97	47.40	45.86	44.79
Tamworth x Native[1]	—	—	—	—

[1] The Tamworth x Native was not represented at 168 days of age.

TABLE 4.—*Average heart girth of the different breeds of swine used, at different ages*

Breed	Trial No.—			
	1	2	3	4
At 56 days of age				
	Inches	*Inches*	*Inches*	*Inches*
Duroc Jersey	23.25	—	24.75	—
Landrace Large Black x Duroc	—	23.12	21.18	23.19
Duroc x Native	—	20.14	21.60	22.42
Tamworth x Duroc	—	—	20.48	—
Native	23.94	22.52	—	21.03
Landrace Large Black x Native	23.64	22.67	22.25	22.47
Tamworth x Native	—	—	19.37	—
At 84 days of age				
Duroc Jersey	27.67	—	26.47	—
Landrace Large Black x Duroc	—	27.33	24.88	28.31
Duroc x Native	—	26.23	26.29	28.14
Tamworth x Duroc	—	—	25.00	—
Native	28.09	26.72	—	25.22
Landrace Large Black x Native	29.62	27.53	26.72	26.89
Tamworth x Native	—	—	23.02	—
At 112 days of age				
Duroc Jersey	33.28	—	29.47	—
Landrace Large Black x Duroc	—	32.61	30.31	33.21
Duroc x Native	—	29.79	30.66	32.64
Tamworth x Duroc	—	—	29.16	—
Native	32.13	31.12	—	30.71
Landrace Large Black x Native	33.98	31.89	31.75	31.42
Tamworth x Native	—	—	26.77	—
At 140 days of age				
Duroc Jersey	38.07	—	32.27	—
Landrace Large Black x Duroc	—	36.70	34.58	37.62
Duroc x Native	—	35.21	33.22	37.36
Tamworth x Duroc	—	—	34.44	—
Native	35.57	35.70	—	35.54
Landrace Large Black x Native	36.83	37.36	35.27	36.17
Tamworth x Native	—	—	30.79	—
At 168 days of age				
Duroc Jersey	41.97	—	34.97	—
Landrace Large Black x Duroc	—	40.69	37.02	42.08
Duroc x Native	—	39.61	38.16	40.42
Tamworth x Duroc	—	—	36.38	—
Native	38.31	39.03	—	39.04
Landrace Large Black x Native	41.75	41.75	39.77	39.46
Tamworth x Native[1]	—	—	—	—

[1] The Tamworth x Native was not represented at 168 days of age.

Large Black x Duroc and Duroc x Native had greater heart girth than the Native and Landrace Large Black x Native.

The average flank girth of the different breeds at each of the trials is given in table 5.

Breed differences were observed in trial 1 at 168 days of age; the Durocs and Landrace Large Black x Native had greater flank girth than the Native. In trial 2 the only significant difference was found at 56 days when the Duroc x Native showed less flank girth than the other breeds, but the significance of the differences disappeared at the later ages.

There were breed differences in trial 3 at all ages; from 56 to 140 days of age, the Tamworth x Native was inferior to all other breeds in flank girth; the Durocs started with greater flank girth than the other breeds, but at 112, 140, and 168 days of age, the Landrace Large Black crossbreds and the Duroc x Native had flank girth exceeding that of the Durocs and Tamworth x Duroc. There were no significant differences in trial 4, although the tendency was for the Landrace Large Black x Duroc and the Duroc x Native to have greater flank girth than the Native and Landrace Large Black x Native.

VARIATION IN MEASUREMENTS

The standard deviations and coefficients of variation of the different measurements at the different ages were calculated using the data obtained from the 66 barrows considered. Although the barrows were of different breeds, it was thought that the information gathered might be of value to Puerto Rican swine producers. Most swine herds in Puerto Rico include several breeds or a mixture of breeds. The present insufficiency of pork production necessitates that emphasis be placed upon quantity rather than quality.

The coefficient of variation decreased from the 56- to the 168-day measurements. The information is summarized in table 6.

As shown in table 7, Goodbey, et al, (3), reported the mean and the coefficients of variation at 56, 112, and 168 days for weight, length, and heart girth of 100 Berkshire barrows.

Although Godbey et al (3) worked with Berkshire barrows, it is surprising how close their means are to those obtained in this study. However, the pigs considered here varied more in weight, length, and heart girth, probably because several breeds were represented and the information was collected from different trials.

Winters (6) reported the measurements shown in table 8 at 24 weeks for Poland China and Minnesota No. 1 boars and barrows.

The pigs studied here showed greater length and less girth at 168 days than those considered by Winters.

TABLE 5.—*Average flank girth of the different breeds of swine used, at different ages*

Breed	Trial No.—			
	1	2	3	4
At 56 days of age				
	Inches	*Inches*	*Inches*	*Inches*
Duroc Jersey	24.11	—	25.28	—
Landrace Large Black x Duroc	—	23.90	22.95	24.27
Duroc x Native	—	22.09	23.20	23.36
Tamworth x Duroc	—	—	20.60	—
Native	25.25	24.16	—	21.47
Landrace Large Black x Native	24.85	24.88	24.61	23.11
Tamworth x Native	—	—	19.45	—
At 84 days of age				
Duroc Jersey	29.44	—	26.56	—
Landrace Large Black x Duroc	—	28.83	25.92	30.50
Duroc x Native	—	28.56	27.63	30.83
Tamworth x Duroc	—	—	25.83	—
Native	31.11	29.52	—	28.19
Landrace Large Black x Native	31.99	29.19	28.00	29.14
Tamworth x Native	—	—	23.33	—
At 112 days of age				
Duroc Jersey	34.46	—	28.38	—
Landrace Large Black x Duroc	—	33.69	31.64	34.23
Duroc x Native	—	32.34	32.52	34.20
Tamworth x Duroc	—	—	29.14	—
Native	34.42	33.75	—	33.04
Landrace Large Black x Native	36.09	33.75	32.83	31.61
Tamworth x Native	—	—	27.70	—
At 140 days of age				
Duroc Jersey	39.47	—	30.44	—
Landrace Large Black x Duroc	—	37.26	36.66	39.15
Duroc x Native	—	37.00	35.54	39.72
Tamworth x Duroc	—	—	33.91	—
Native	37.90	38.13	—	36.08
Landrace Large Black x Native	39.21	39.86	37.19	38.39
Tamworth x Native	—	—	27.70	—
At 168 days of age				
Duroc Jersey	43.68	—	36.22	—
Landrace Large Black x Duroc	—	41.37	40.41	42.46
Duroc x Native	—	40.12	38.88	42.53
Tamworth x Duroc	—	—	35.61	—
Native	40.48	41.57	—	41.13
Landrace Large Black x Native	43.47	43.10	40.22	41.33
Tamworth x Native[1]	—	—	—	—

[1] The Tamworth x Native was not represented at 168 days of age.

TABLE 6.—*Standard deviations and coefficients of variation of measurements and weights at different ages for barrows of all breeds used in these experiments*

Measurements[1]	Mean	Standard deviation	Coefficient of variation
			Percent
56-day weight	29.05 lb.	6.224 lb.	21.43
56-day length	24.66 in.	2.011 in.	8.15
56-day heart girth	22.02 in.	1.958 in.	8.89
56-day flank girth	23.14 in.	2.406 in.	10.40
84-day weight	55.43 lb.	11.155 lb.	20.12
84-day length	31.32 in.	2.353 in.	7.51
84-day heart girth	26.60 in.	2.281 in.	8.58
84-day flank girth	28.29 in.	3.223 in.	11.39
112-day weight	88.83 lb.	15.504 lb.	17.45
112-day length	37.11 in.	2.645 in.	7.13
112-day heart girth	30.90 in.	2.815 in.	9.11
112-day flank girth	32.27 in.	3.465 in.	10.74
140-day weight	129.49 lb.	19.349 lb.	14.94
140-day length	42.07 in.	2.296 in.	5.46
140-day heart girth	35.43 in.	2.595 in.	7.33
140-day flank girth	37.14 in.	3.413 in.	9.19
168-day weight	173.04 lb.	21.731 lb.	12.56
168-day length	45.24 in.	2.001 in.	4.42
168-day heart girth	39.04 in.	2.749 in.	7.04
168-day flank girth	40.67 in.	3.430 in.	8.43

[1] 66 barrows at 56 days and 84 days; 65 barrows at 112 days; 62 barrows at 140 days; 50 barrows at 168 days.

TABLE 7.—*Mean and coefficients of variation at 56, 112, and 168 days for weight, length, and heart girth of 100 barrows, as follows, as reported by Godbey et al*

Measurement	Mean	Coefficient of variation
		Percent
56-day weight	31.86 lb.	19.90
112-day weight	96.31 lb.	17.56
168-day weight	174.52 lb.	10.93
56-day length	24.45 in.	6.30
112-day length	35.85 in.	5.91
168-day length	44.63 in.	3.93
56-day heart girth	21.50 in.	6.81
112-day heart girth	30.59 in.	6.83
168-day heart girth	38.19 in.	5.16

CORRELATION BETWEEN MEASUREMENTS AND WEIGHTS

The correlation between the measurements and the weights and between the different measurements are shown in tables 9 and 10.

Except for length and weight at 168 days of age, the correlations found in this study are much lower than those reported by Godbey et al (3) for length, heart girth, and weight at 56, 112, and 168 days of age. The reason for this may have been, again, that different breeds were represented.

TABLE 8.—*Length, heart girth, and flank girth measurements of Poland China and Minnesota No. 1 boars and barrows, as reported by Winters*

Breed and sex	Length	Heart girth	Flank girth
Poland China:			
Barrows	39.987	40.416	41.876
Boars	40.300	40.193	41.037
Minnesota No. 1:			
Barrows	42.280	43.293	43.500
Boars	41.360	39.827	39.720

TABLE 9.—*Correlation between length, heart-girth, and flank-girth measurements and weights at different ages of swine used in this study*

Age (days)	Length and weight	Heart girth and weight	Flank girth and weight
56	0.236	0.284	0.278
84	.376	.234	.132
112	.511	.497	.272
140	.546	.513	.504
168	.763	.531	.356

TABLE 10.—*Correlation between length, heart-girth, and flank-girth measurements at different ages of swine used in this study*

Age (days)	Length and heart girth	Length and flank girth	Heart girth and flank girth
56	0.663	0.677	0.884
84	.725	.687	.910
112	.544	.468	.911
140	.369	.318	.895
168	.391	.239	.808

ESTIMATES OF WEIGHT FROM MEASUREMENT

The weight of hogs at 168 days of age can be estimated with some accuracy from their length, heart girth, and flank girth. The equation to be used is: $Y = 7.058\,X_1 + 2.611\,X_2 - 0.420\,X_3 - 231.096$, wherein X_1 stands for the length in inches, X_2 for the heart girth in inches, and X_3 for the flank girth in inches. The multiple correlation coefficient upon which the equation

is based, 0.805, is highly significant statistically. Similar estimates could be made for other ages, but with less accuracy than at 168 days of age.

PREDICTION OF WEIGHT FROM MEASUREMENTS

The following tabulation shows the multiple correlation coefficients for the prediction of weight at 168 days of age by using different measurements and weight of weaning:

Measurements	*R*
Weaning weight + length + flank girth + heart girth	0.7120
Weaning weight + length + flank girth	.7052
Weaning weight + length	.7047
Weaning weight	.6516
Weaning length	.5989

The weight at 168 days of age can be predicted with some accuracy by using the weaning weight alone. The accuracy of the prediction is increased, however, when the value for length at weaning is added. No noticeable additional accuracy is attained by using either heart girth or flank girth at weaning, or both measurements. The equation for the prediction of weight at 168 days from the weight and length of the pigs at weaning is: $Y = 4.2919\ X_1 + 1.7175\ X_2 + 19.1073$, wherein X_1 is the length in inches and X_2 is the weaning weight in pounds.

Comstock, et al (2), stated that weaning weight is but a poor criterion of inherited ability to grow and that heavy weaning pigs gain more in the period from 56 days on, because they are heavier at the beginning of that period. This would be an important consideration in selecting breeding stock, but is of much less importance when the aim is to select fast-growing animals from a group of weaned pigs.

Conclusions

The crossbreds, Landrace Large Black x Duroc, Duroc x Native, and Landrace Large Black x Native, had greater length, flank girth, and heart girth than the Native and, in most cases, than the Duroc. The Tamworth crosses were inferior to the other breeds in these measurements. These results correspond to those obtained with weight data, reported by González Chapel and Cabrera (4).

If due consideration is given to the initial disadvantage of the barrows as compared with the boars, practically no difference in measurements was found between the sexes. The statistically significant differences observed could be well explained by the initial difference which was probably attributable to factors extraneous to the individuals themselves. However, the importance of sex as a factor influencing the growth and body form of swine has been well established at the Minnesota Agricultural Experiment Sta-

tion. The fact that the pigs in this study were fed individually may account, in part, for the better performance of the boars as compared with the barrows at the later age groups.

The variation within the measurements and within the weights was definitely higher than that found by Godbey et al (3), at Clemson Agricultural College, but that could be ascribed to the many breeds represented in this study.

The gain in length of the pigs of all breeds and sexes from weaning to 168 days of age corresponded more closely to the gain in weight than to the gain in heart or flank girth.

Accuracy in predicting the weight of hogs at 168 days of age from information obtained at weaning time can be increased appreciably by the use of the value for the length of the pigs at weaning. Heart-girth and flank-girth measurements add practically nothing to the accuracy of the prediction obtained from the values for weaning weight and weaning length. The use of the weaning weight for the 154-day weight prediction has been suggested already by González Chapel and Cabrera (4).

Summary

The length, heart girth, and flank girth of 66 boars and 66 barrows of different breeds and crossbreds were compared with their weight at weaning, and at 84, 112, 140, and 168 days.

There were important measurement differences between the breeds. Differences in measurement between the boars and the barrows could be explained by their initial difference at weaning.

It was found that accuracy in selecting pigs at an early age for breeding or subsequent rearing can be increased by using the length measurement along with the weight of the animals at weaning to predict weight at 168 days of age.

The use of heart or flank measurements does not increase the accuracy of the prediction.

The coefficients of correlation and variation for the different measurements are given for the ages studied.

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MINIMUM NUTRITIVE REQUIREMENTS OF DAIRY CATTLE UNDER TROPICAL CONDITIONS

J. I. Cabrera[1]

Introduction

The literature on the minimum requirements of dairy cattle under tropical conditions is very scarce. This is because tropical agricultural workers have relied considerably on the research findings of their fellow workers of the Temperate Zone. For a long time the animal husbandman in the Tropics has relied on Morrison's Standards for nutritional requirements, but practical findings have demonstrated that these are not appropriate for the conditions prevailing in this region.

With this in mind, a series of feeding and digestion trials were conducted to determine the minimum requirements in therms, for growing heifers, dry dairy cows, and producing dairy cows.

The report that follows is a preliminary one. More research is needed and is under way, to provide final answers.

Method of Procedure

The method used in determining the minimum requirements for dairy cattle is the one suggested by Dr. R. W. Swift of the Institute of Animal Nutrition at the Pennsylvania State College, in a personal interview with the author in September 1950.

Experimental Results

growth requirements

The heifers used weighed an average of 611 pounds with a range from 495 to 712 pounds. The group of 10 heifers were grade Holsteins and Native animals. These heifers were placed on a ration consisting of Merker grass about 70 days old. The heifers received all the grass they could eat. Daily weighings were taken. A balance between the grass intake and body weight was obtained in about 10 days. After the animals reached this point the ration was left unchanged and feces and grass samples were taken for 7 days in succession. The heifers were weighed daily during this collection period.

After the feces and roughage samples were taken they were dried and burned in the bomb calorimeter to determine their energy value. From these values the following equation was determined (see fig. 1):

$$Y = 29.023\,X - 3{,}547$$

[1] Assistant Animal Husbandman, Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P. R.

The analysis of variance to show the fitness of the equation is shown below:

Source of variation	*DF*	*SS*	*V*	*F*
Total	9	60,532,709		
Regression	1	33,640,356	33,640,356	10.00*
Error	8	26,892,353	3,361,544	

The regression on the equation is significant at the 5-percent point. From this equation the requirements for heifers weighing from 495 to 712 pounds

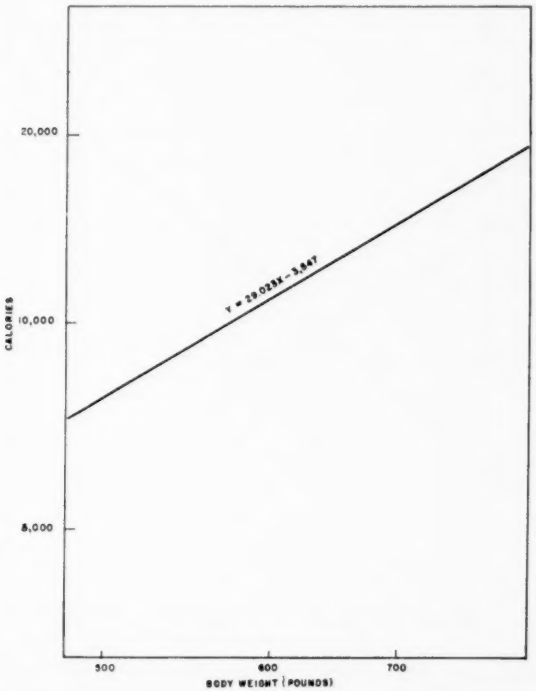

FIG. 1.—Growth requirements of heifers at different body weights.

which varied from 10.82 to 17.12 therms can be determined. These requirements are about 1.5 or 2 times the requirements reported by Morrison.

MAINTENANCE REQUIREMENTS

In determining the minimum requirements of dry dairy cows the same procedure used with heifers was followed. The cows weighed an average of 860 pounds with a range from 701 to 1,018 pounds. The equation determined was as follows (see fig. 2):

$$Y = 38.76\,X - 20{,}576.60$$

The following analysis of variance to determine the fitness of the equation shows that the regression was highly significant at the 1-percent point:

Source of variation	*DF*	*SS*	*V*	*F*
Total	13	287,786,624		
Regression	1	136,847,955	136,847,955	10.88**
Error	12	150,938,669	12,576,222	

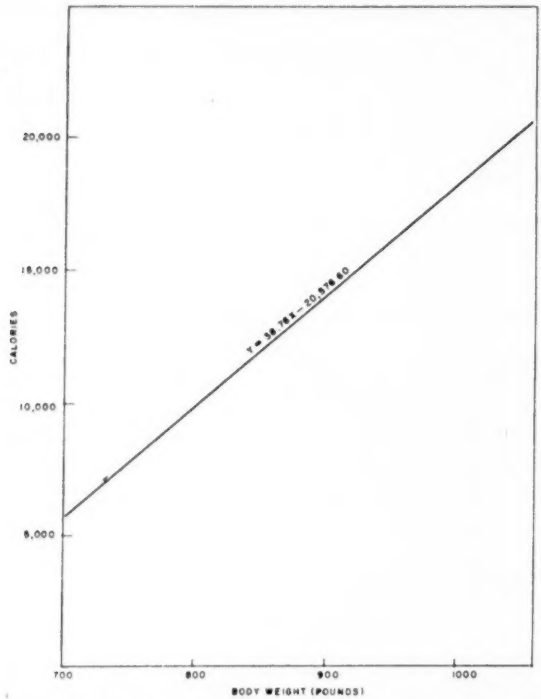

FIG. 2.—Maintenance requirements of mature dairy cows of different body weights.

From this equation the requirements of dry dairy cows weighing from 701 to 1,018 pounds can be determined as follows: 6.594 therms for 701 pounds and 18.9198 therms for 1,018 pounds. These findings are about 1.5 and 2 times the requirements reported by Morrison.

PRODUCTION REQUIREMENTS

In determining the requirements of dairy cows producing from 16 to 33 pounds of FCM milk the requirements for maintenance determined previously were used. The roughage fed was Merker grass which was hand-fed in quantities weighed daily. All forage and concentrate consumption was

recorded. Forage and concentrate samples were taken for calorimetric determinations.

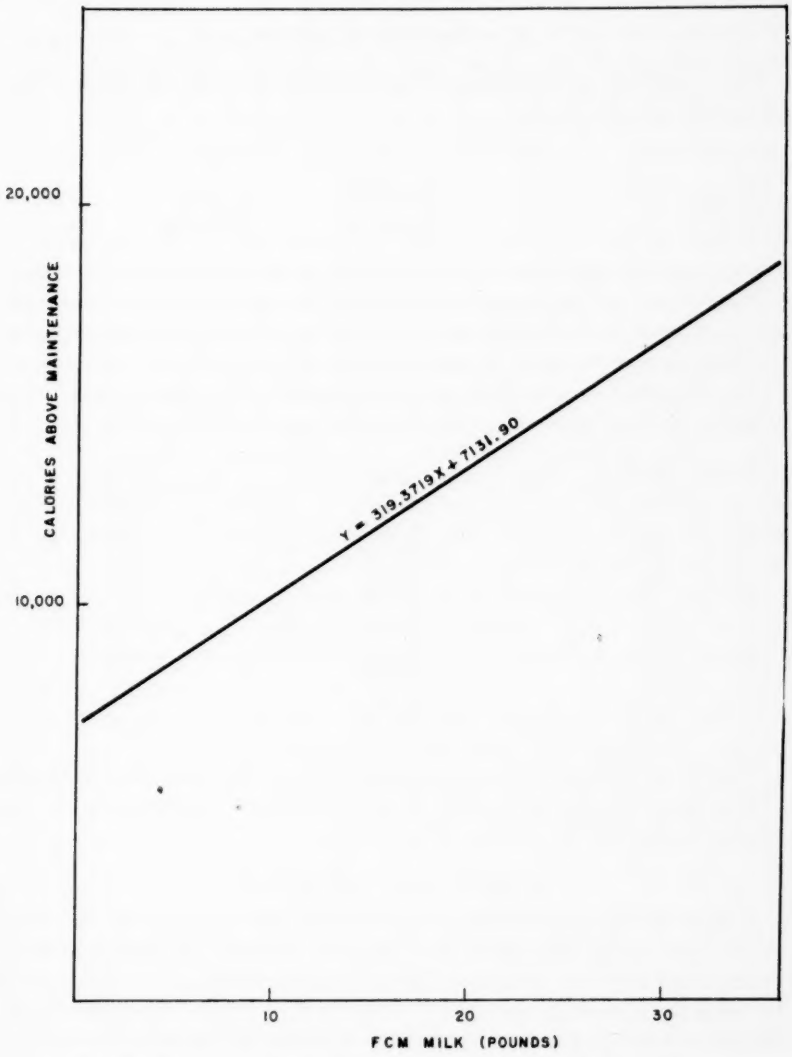

FIG. 3.—Requirements of milking cows of different body weights.

The caloric value of the feed used was 2,004.15 calories per pounds with a coefficient of digestibility of 0.7840.

Exactly the rame procedure reported previously was followed with this group of cows.

The equation obtained was as follows (see fig. 2):

$$Y = 319.3719 + 7{,}131.90$$

The analysis of variance shown below indicates that the regression of the equation is not significant:

Source of variation	*DF*	*SS*	*V*	*F*
Total	5	67,145,475		
Regression	1	16,240,841	16,240,641	1.28
Error	4	50,894,833	12,723,708	

Although the regression was not significant, there is an indication that the nutritional requirements for milk production under tropical conditions are again about 1.5 to 2 times those reported by Morrison. In this phase of the problem more research is needed with a larger number of cows.

The following results showing requirements above maintenance were obtained for cows producing from 16 to 33 pounds of FCM milk:

FCM milk Pounds	*Therms*	*Therms per pound*
16	12.242	0.765
18	12.881	.716
20	13.519	.676
22	14.158	.644
24	14.797	.617
26	15.435	.594
28	16.074	.574
30	16.713	.557
32	17.352	.542
34	17.991	.529

There is an indication that the higher producers are more efficient in feed utilization. It was found also that the addition of concentrates to the ration educed its digestibility about 9.58 percent.

Summary and Conclusions

A series of digestion trials was conducted in order to determine the minimum requirements for growth, maintenance, and milk production of dairy cattle under tropical conditions. The growth requirements were determined by using the following equation: $Y = 29.023\ X - 3{,}547$. This equation was determined by using heifers weighing from 495 to 712 pounds. The requirement varied from 10.82 to 17.12 therms.

The maintenance requirements can be determined by solving the equation: $Y = 38.76\ X - 20{,}576.60$. The cows used to determine this equation weighed from 701 to 1,018 pounds. The therm requirements varied from

6.594 to 18.92. The production requirements above maintenance were studied also and the equation: $Y = 319.3719\,X + 7{,}131.90$ was worked out, but the regression was not significant.

This preliminary report on minimum requirements indicates that the energy required for growth and maintenance is about 1.5 to 2 times the requirements reported by Morrison. The addition of concentrates to the ration reduced its digestibility 9.58 percent.

In all cases the X of the equations above represents the live weight of the animals used. Y represents the total calories needed.

Resumen

Se hizo una serie de pruebas de digestibilidad con el propósito de determinar los requisitos mínimos para crecimiento, mantenimiento y producción de leche de ganado vacuno bajo condiciones tropicales. Los requisitos mínimos para crecimiento se pueden determinar usando la fórmula: $Y = 29.023\,X - 3{,}547$. Esta ecuación fué determinada usando novillas que pesaron entre 495 y 712 libras. Los requisitos de mantenimiento se pueden determinar resolviendo la ecuación de: $Y = 38.76\,X - 28{,}576.60$. Las vacas usadas para determinar esta ecuación pesaron entre 701 y 1,018 libras. Los requisitos térmicos variaron entre 6.594 y 18.92. Se estudiaron también los requisitos para producción por encima de los requisitos de mantenimiento. Se trabajó la fórmula siguiente: $Y = 319.3719\,X + 7131.90$ pero la regresión no fué significativa. Este informe preliminar de los requisitos mínimos de energía necesaria para crecimiento y mantenimiento es de 1.5 a 2 veces la cantidad informada por Morrison.

La presencia de concentrados redujo la digestibilidad de la ración en 9.58 por ciento.

En todos los casos, en las ecuaciones arriba indicadas X representa el peso de los animales y Y representa el número total de calorías.

THE UTILIZATION OF GRASSES, LEGUMES, AND OTHER FORAGE CROPS FOR CATTLE FEEDING IN PUERTO RICO

III. COMPARISON OF FERTILIZED GUINEA GRASS, PARA GRASS, TROPICAL KUDZU AND GUINEA GRASS, AND TROPICAL KUDZU

L. Rivera Brenes, F. J. Marchán, and J. I. Cabrera[1]

Introduction

This paper reports the third of a series of grazing trials started in 1945 for the evaluation of the most important pasture crops found in the Island and of those introduced.

As recommended by the Joint Pasture Research Committee (1)[2] a duration for pasture experiments of 6 to 10 years is preferable, but we think that under our conditions, where we have some 365 grazing days annually, such a long time is not needed to get reliable results. The only large climatic variation in the Island is in rainfall. There is a 2- or 3-month dry period during the year, especially in the southern part of the Island. The northern part of the Island has been fortunate in this respect for the past 3 years.

The results of these grazing trials have been reported individually in order to have the information available to the farmers as soon as possible. After the end of the fourth trial, finished in 1950, all the data will be compiled in one final report.

Literature Review

In the first grazing trial (2) the carrying capacity of the Para grass-tropical kudzu mixture was 1 head and in the second trial (3) it was also nearly 1 head per acre. Unfertilized Guinea grass had a carrying capacity of 0.5 in the first trial and for the second trial; when fertilized, its carrying capacity was increased to 1.12 heads per acre.

In these two trials it was also found that fertilization increases the protein content as well as the total tonnage. Planting a legume in association with the grass not only increases both the yield and the protein content of the grass, but also renders both far more uniform.

Procedure

The procedure followed was the same as that for the first trial (2). The grasses compared were mixtures of Para grass-kudzu, Guinea grass-kudzu,

[1] Acting Head, Animal Husbandry Department, Assistant Chemist, and Assistant Animal Husbandman, respectively, Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P. R.

[2] Numerals in parentheses refer to Literature Cited, p. 113-14.

and Guinea grass alone. This time Guinea grass was fertilized with 100 pounds of ammonium nitrate per acre at the beginning of the trial and a second application of 200 pounds of ammonium sulfate per acre 3 months later. To save time in the establishment of the Guinea grass-kudzu mixture, the Guinea grass was planted in the old kudzu stand. The land was not plowed, to avoid killing the already established kudzu, but was furrowed with a small plow at the proper distance. Pieces of roots were used and in 7 months an excellent Guinea grass-kudzu mixture was obtained.

The heifers used were Holstein-Native, Brown-Swiss-Native crosses, and pure-bred Holsteins. They were distributed among the grasses to avoid breed differences. The trial lasted 221 days, and was divided into three periods, according to the number of animals grazing each grass at one time. During the first and third periods there were 2 heifers per acre-plot of grass and during the second period 2 heifers in each acre-plot of Para grass-kudzu and Guinea grass-kudzu and one in each acre of Guinea grass alone. When calculating gain in weight and differences in gain in weight, periods 1 and 3 were combined and analyzed separately from period 2. Total digestible nutrients and carrying capacity were calculated for the trial as a whole, using the coefficients of digestibility recommended by the Pasture Research Committee (1) instead of 72 percent of the dry matter as in previous trials.

Results and Discussion

As in previous reports weight gains and differences are presented in table 1 to show the probable differences in nutritive value between the grasses and legume-grass mixtures.

There was no significant difference between the average gain in weight of the animals that grazed on Para grass-kudzu and on Guinea grass-kudzu mixture for the first and third periods together. The differences between the mean gain in weight in the legume-grass mixtures and Guinea grass alone were significant at the 5-percent level. No significant difference was found between the mean gains in weight during the second period. The most probable explanation of the results obtained in the second period is the following: The Guinea grass plots were fertilized with ammonium sulfate the same day (8–4–48) this second period started. The addition of nitrogen to the soil improved the nutritive value of the grass considerably. This assumption is sustained by the average daily gain in weight per animal. During the first and third periods together the average daily gain on Guinea grass was 0.30 pounds, and for the second period 1.19 pounds; of course, we must consider that the lengths of the periods 158 and 63 days, respectively, might have affected the averages. In general, the daily gain in weight per animal for the first and third periods together for all the roughages in the trial was lower than in the second period, for Para grass-kudzu, 0.68

pounds and 1.09 pounds per animal, and for Guinea grass-kudzu 0.62 pounds and 1.17 pounds, respectively.

The average chemical analyses for the grass samples taken during the grazing trial are presented in table 2.

TABLE 1.—*Gain in pounds per group, mean gain per animal, and least significant difference*

Grasses	Heifers	Initial weight of groups	Weight of groups at end of period	Gain of groups	Mean weight per animal	Least significant differences
First and third periods together 5-12-48 to 8-3-48 and 10-6-48 to 12-18-48						
	Number	*Pounds*	*Pounds*	*Pounds*	*Pounds*	
PK	3	862	1,097	235	78.33	
PK	3	1,270	1,677	407	135.67	
GK	3	761	1,008	247	82.33	69.12 at 5-percent level
GK	3	1,103	1,444	341	113.67	159.60 at 1-percent level
G	3	932	1,052	120	40.00	
G	3	832	1,004	172	57.33	
Second period 8-4-48 to 10-5-48						
PK	3	1,279	1,451	172	57.33	
PK	3	1,229	1,469	240	80.00	
GK	3	1,059	1,278	219	73.00	45.75 at 5-percent level
GK	3	1,273	1,499	226	75.33	
G	3	1,004	1,228	224	74.66	

[1] The final weights for these animals were taken as the initial weight plus the gain in weight during the first and third periods because the second period was analyzed separately.

TABLE 2.—*Average analysis of the three forage crops during the whole trial on a dry basis*

Grasses	Samples	Moisture	Ash	Crude protein	Fat	Fiber	Nitrogen-free extract
	Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
PK	33	75.86	8.58	9.83	1.34	32.10	48.25
GK	33	76.64	9.52	8.34	1.19	35.85	45.12
G	33	70.24	9.43	5.21	1.07	36.11	48.12

The crude-protein content of the legume-grass mixtures is higher than that of the grass alone. This is to be expected, and was true in this and the previous trials (1–3). Guinea grass received only two fertilizations instead of three, as was the case in the second experiment. The reason for this was

that fertilizer was applied according to the condition of the grass that is, its color and growth. In trial No. 2 (3) the average protein in the Guinea grass was 8.56 per cent and in this trial only 5.21 percent, dry basis. This might be attributed to the fertilizer received during the experimental periods, and also to the difference in quality of the samples taken from the clippings. The grass received only two applications of nitrogen because, as pointed out above, observations indicated that it was green and having good growth.

The crude protein of the mixture of Guinea grass and kudzu compares very well with the over-all content for fertilized Guinea grass in trial No. 2 (2), 3.34 and 8.56 per cent, respectively. The results obtained emphasize the importance of the legumes in grass mixtures.

Nothing was clipped from the Para grass-kudzu plots during the entire experimental period. Table 3 presents the data for clippings from the other two roughages and their dry-matter content. No residue was clipped during the third period in any of the roughages.

TABLE 3.—*Clippings and dry-matter content of the grasses in pounds, by periods*[1]

Grasses	First period		Second period	
	Clippings	Dry matter	Clippings	Dry matter
	Pounds	*Pounds*	*Pounds*	*Pounds*
PK	—	—	—	—
GK	20,303	4,742.78	750	175.20
G	3,908	1,663.02	5,929	1,764.47

[1] No clippings in the third period.

As pointed out in the procedure, the Guinea grass was planted in the old kudzu stand, hence was favored by a large accumulation of nitrogen in the soil. The growth obtained during the pre-experimental period was exuberant. Of the 20,303 pounds of clippings from the Guinea grass-kudzu mixture during the first period, 18,810 pounds were obtained after the first rotation in the 3 acres. From then on the heifers ate nearly all the roughage produced. This is demonstrated by the small quantity obtained in the second period, and none in the third.

The effect of the fertilization of the Guinea grass is shown by the increase in the quantity of clippings in the second period as compared with the first. An application of ammonium sulfate was made just at the start of the second period.

The calculated carrying capacity is presented in table 4.

Although the Guinea grass plots looked in good condition with only two applications of nitrogen, the carrying capacity was lower than in trial No. 2 (3). Apparently two applications of nitrogen were not enough to maintain the grass as in the previous trial. It is the opinion of the investigator that

these variations can be expected because of the different animal and climatic factors affecting the results. Analyzing periods Nos. 1 and 3 (158 days) separately from period No. 2, (63 days) the carrying capacity was 0.58 and 0.92, respectively. The results in the second trial demonstrate the favorable effects of nitrogen fertilization. The same thing had been happening with the Para grass-kudzu mixture, although the variation was not great. The results obtained with the mixture of Guinea grass-kudzu are encouraging; kudzu mixes very well with the grass and there was no sign of incompatibility, but further trials are need to determine this.

TABLE 4.—*Approximate carrying capacity for the grasses on trial*

Grass	Cow-days	Days on trial	Carrying capacity
		Days	*Head*
PK	169.73	221	0.77
GK	241.61	221	1.09
G	149.70	221	.68

The statistical analysis of the calculated total-digestible-nutrient yields is given below for the entire experimental period:

Grasses:	T.D.N. mean yield per acre: *Pounds*
PK	2,898.33
GK	3,939.66
G	2,379.33
L.S.D.	949.67 at 5-percent level

There was no significant difference at the 1-percent level.

The mixture of Guinea grass-kudzu was superior in T.D.N. yield to the other forages tested. This resulted, of course, from the larger quantity of clippings during the first period. As explained before, the Guinea grass in the mixture had the benefit of the accumulation of nitrogen in the soil which produced an exuberant growth before the experiment started. When the heifers were put to graze on it they were not able to eat all the roughage at the time the other grass subplots were due for rotation. There was no significant difference between Guinea grass alone and Para grass and kudzu.

The rainfall figures for the 8 months of the trial are shown in the following tabulation from records kept by the Experiment Station farm:

Month	*Rainfall (Inches)*	*Month*	*Rainfall (Inches)*
May	10.91	September	10.07
June	8.01	October	4.14
July	8.79	November	9.69
August	7.33	December	9.85
		Total	58.79

The water supply was more or less the same as for the previous trial. The monthly average was 7.35 inches of rainfall, which eliminates this as a factor affecting growth.

Everything tends to indicate that the mixture of Guinea grass and kudzu is a good combination for pasture. They mix well and apparently there is no incompatability, but because Guinea grass is better adapted to dry areas, it needs further investigation in other places around the Island.

The results obtained for Para grass-kudzu vary somewhat from those obtained before (1–3). As this is something to be expected, and the difference is not great, it is the opinion of this investigator that this roughage has been performing uniformly throughout.

There is no doubt as to the benefits of nitrogen fertilization of grasses; this has been demonstrated in two consecutive trials with Guinea grass. But in the long run, the use of a legume will be more economical from all points of view.

Summary and Conclusions

A third grazing trial of 221 days was conducted under the same procedure as in trial No. 1 (2). A modification was introduced in that the calculation of T.D.N. was made using the chemical analysis of the roughages, and the digestion coefficients given by the Pasture Research Committee (1).

The grasses under trial were, Para grass-kudzu, in its third year, Guinea grass-kudzu, in its first year, and fertilized Guinea grass, and its second year. In this experiment Guinea grass received only two applications of nitrogen instead of three as in trial No. 2. According to our observations this was because the grass was growing well and had a nice green color. Nitrogen was applied when the leaves began turning yellowish.

Para grass-kudzu was uniform in performance, the carrying capacity being 1 head in the first trial, 1 head in the second, and 0.77 head for this trial. The carrying capacity of the mixture of Guinea grass and kudzu was 1.09, but since this grass was planted in the old kudzu stand, it received the benefits of the nitrogen accumulation in the soil producing an exuberant growth at the beginning of the trial. As a result, larger quantities of residue were clipped after rotations affecting the carrying capacity favorably. Although the results are encouraging, further investigations are needed to to make definite recommendations.

Guinea grass alone had a carrying capacity of 0.68 head. It was lower than in the previous trial. The difference can be attributed to the difference in nitrogen supplied, as nitrogen increases the quantity of roughage produced and its nutritive value.

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ENVIRONMENTAL INFLUENCE ON THE EGG SIZE OF PULLETS IN PUERTO RICO

A. González Chapel and M. Rojas[1]

Introduction

The study of the fluctuation in the curve of egg size for pullets in Puerto Rico is interesting when considered as part of the general evaluation of the effect of the tropical environment on egg production. González Chapel and Rojas (3)[2] had already observed an important influence of the time of hatching on the sexual maturity of a similar group of pullets in Puerto Rico.

The depressive effect of high temperatures on egg size has been reported by some workers in the United States. Bennion and Warren (1) found that the mean weekly egg weight when compared with the mean maximum weekly temperature showed a sharp decline when the temperature was above 85° F. The mean daily egg size of birds placed under controlled temperature was reduced 15 or 20 percent by high temperatures. The egg size declined much more rapidly under high temperature than it increased when the temperature was lowered. Warren (8) secured data on egg size from 11 localities in latitudes extending from the Equator to as far north as Scotland and concluded that excessively low temperatures seemed to have no effect on egg size, but after the daily maximum temperatures had exceeded 70° F. for a few days, egg-size fluctuations usually showed a close correlation with those of temperature. Lorenz and Almquist (6) found evidence of a decrease in egg weight proportional to the increase in temperature between 40° and 90° F.

The average temperature in Puerto Rico is relatively uniform, the mean annual temperature being 76°, with an average minimum annual temperature of 66.9° and an average maximum annual temperature of 86° F. (4).

Experimental Methods

This study was made at the La Plata Animal Production Substation of the Agricultural Experiment Station; included in it were 206 pullets which laid throughout 1947–48. The breeds represented were the New Hampshire, with 124 birds; the White Leghorn, with 27 birds; and crossbreds of New Hampshire x Native and White Leghorn x Native, identified as Lines 1, 3, 5, and 6, with 51 birds. The birds were distributed in 18 groups according

[1] Associate Animal Husbandman and Assistant Animal Husbandman, respectively, Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P. R.

[2] Numerals in parentheses refer to Literature Cited, page 120–21.

to the month in which they started laying. These groups were as follows: New Hampshire—August, September, October, November, December, January; White Leghorn—August, September, November; Line 1—August October, November; Line 3—August; Line 5—August, September, November; Line 6—November, December.

Line 1 and Line 5 birds were New Hampshire x Native crossbreds and Line 3 and Line 6 birds were White Leghorn x Native crossbreds.

Of these 18 groups only 15 were considered in the statistical analysis. The other 3 groups—Line 5 in November, Line 1 in August, and White Leghorn

TABLE 1.—*Monthly average egg size in ounces per dozen for New Hampshire birds which were of different ages at sexual maturity and started laying in different months*

Month birds started to lay	Egg size in ounces per dozen for—					
	9 birds, sexual maturity at 182.4 days	37 birds, sexual maturity at 190.9 days	26 birds, sexual maturity at 212.9 days	23 birds, sexual maturity at 233.1 days	14 birds, sexual maturity at 274.5 days	15 birds, sexual maturity at 301.2 days
August	18.01					
September	19.29	18.11				
October	20.29	19.49	19.76			
November	21.27	20.30	20.55	20.38		
December	21.90	20.85	21.40	21.07	21.42	
January	22.26	21.66	21.70	21.66	22.15	21.70
February	22.55	21.86	22.01	21.96	22.25	22.05
March	22.84	22.05	22.38	22.24	22.65	22.43
April	22.47	21.83	22.02	22.05	22.59	22.00
May	22.54	21.82	22.39	22.38	22.79	22.22
June	23.59	22.26	22.81	22.69	23.94	22.46
July	23.74	22.31	22.50	22.19	22.97	22.87
August		22.46	23.20	23.20	23.53	23.46
September			21.94	22.53	22.68	21.59
October				21.31	21.06	20.38
November					21.31	21.38
December						19.80

in November, were not included because the variation between the months of laying was smaller than the variation between the birds within the month.

Egg size was measured by the weight of the eggs in ounces per dozen. The average egg size during each month was considered a good sample of the potentiality of the bird in respect to egg size for the particular month, regardless of the production during the month. Thus, for the regression studies, 12 average measures of egg size were taken per bird, starting with the first month of laying in each group and up to the twelfth month thereafter.

TABLE 2.—*Monthly average egg size in ounces per dozen for White Leghorn birds which were of different ages at sexual maturity and started laying in different months*

Month birds started to lay	Egg size in ounces per dozen for —	
	5 birds, sexual maturity at 182.6 days	17 birds, sexual maturity at 184.4 days
August	17.49	
September	18.47	17.79
October	19.73	18.84
November	20.25	19.05
December	21.86	20.29
January	21.86	20.83
February	22.32	21.12
March	22.05	21.40
April	22.06	20.67
May	21.85	20.73
June	22.56	21.79
July	22.32	21.34
August		22.20

TABLE 3.—*Monthly average egg size in ounces per dozen for birds of Lines 1, 3, 5, and 6 which were of different sexual maturity and started laying in different months*

[Numerals in boldfaced type indicate month birds started laying]

Month	Egg size in ounces per dozen for —					
	9 birds, Line 1, sexual maturity at 214.8 days	10 birds, Line 3, sexual maturity at 163.5 days	3 birds, Line 5, sexual maturity at 178 days	3 birds, Line 5, sexual maturity at 194.3 days	6 birds, Line 6, sexual maturity at 211.2 days	8 birds, Line 6, sexual maturity at 231.9 days
January	19.79	20.35	18.91	19.11	18.37	18.50
February	20.02	20.28	19.24	19.70	19.28	19.24
March	20.29	20.45	19.97	20.34	18.95	19.18
April	21.00	19.75	20.15	19.81	19.29	19.30
May	20.80	20.38	21.50	19.49	19.68	19.53
June	21.47	20.54	19.99	20.45	18.64	20.33
July	21.89	20.74	20.25	20.56	19.42	20.53
August	21.87	**16.37**	**16.20**	20.43	20.32	20.06
September	21.44	17.34	18.08	**16.79**	19.14	18.56
October	19.14	18.31	18.09	17.91	18.13	17.77
November	**18.80**	18.76	18.35	18.32	**17.61**	17.52
December	19.52	19.35	18.61	18.49	18.14	**18.85**

EXPERIMENTAL RESULTS

In tables 1 to 3 the monthly average egg size, expressed in ounces per dozen eggs, is shown for the different breeds under study. The breeds dif-

fered among themselves in respect to egg weight. A similar breed difference had already been reported by González Chapel (2). Eggs from the New Hampshire and White Leghorn birds weighed more than those of the cross-bred birds.

In all breeds represented in more than one month the egg size increased progressively during the first month of laying according to the month in which laying started. In the New Hampshire breed the first-month egg weight was lowest in August and greater in January. In the other breeds it

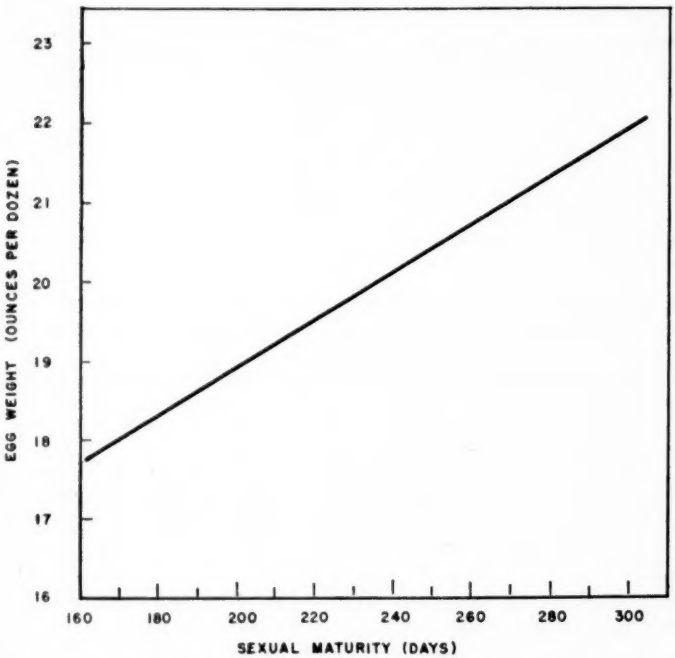

FIG. 1.—Regression of first-month egg size on sexual maturity for New Hampshire birds.

was lowest in August and greater in the subsequent months. This was attributable to the sexual maturity of the birds. The regression of the first-month egg weight on the sexual maturity of the birds is shown in figure 1.

González Chapel (2) found significant correlations between sexual maturity and egg weight in New Hampshire, White Leghorn, and Native birds. He concluded that these correlations probably occurred because of the larger body size of the late-maturing birds at the time of laying their first

egg. Jull (5) says that the earlier in life laying commences, the smaller the size of the birds, on the average, and the smaller the size of the egg, on the average.

The curves of egg size for all the breeds are shown in figure 2.

The egg size increased progressively during the first months of laying and maximum egg size was attained from May to June in most of the groups. In the summer months there was a definite downward drop in egg weight. According to Jull (5), there is an increase in size or weight of eggs laid during the first laying year in most flocks in the United States from the time that laying commences up to the spring of the year. Maximum egg

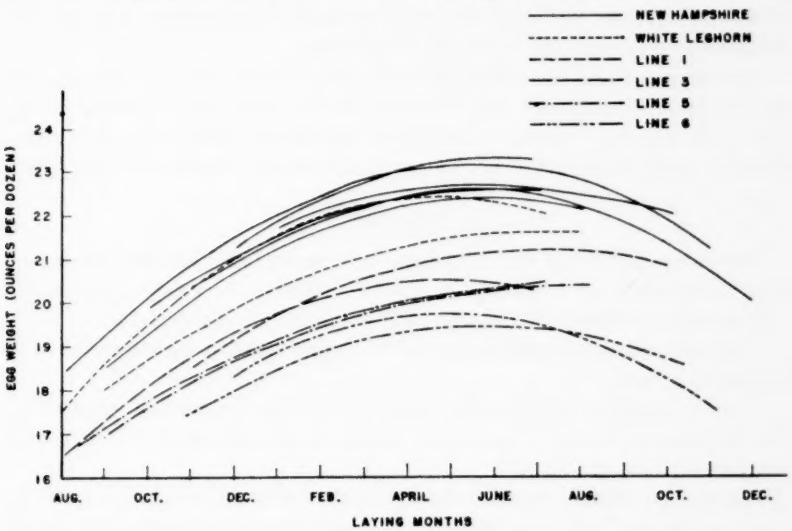

FIG. 2.—Egg size during the first laying year for different breeds and crossbreds as indicated.

weight is usually attained in February or March; during the late spring and the summer there is often a slight relative decline followed by an increase at the close of the first-laying year.

The shape of the curve was the same for most of the groups within each breed, regardless of the month in which laying started. Although the breeds differed between themselves in respect to egg size, the shape of the curve was also similar for most of them.

In some of the groups of the birds, especially in the New Hampshire breed, egg size tended to decline from March to April and to increase again from April to May. But this slight tendency was smoothed out in the statistical curve.

Discussion

The results of this study seem to agree with the findings of Warren et al (9) at the Kansas State College. They studied groups of birds under a controlled environment. They concluded the evidence was clean-cut that egg size was depressed by temperature in the hotter summers. If the hens were not subjected to high summer temperatures, egg size increased throughout the entire first laying year. They also concluded that a constant temperature of 65° F. is too high for maximum egg size.

The warmer temperature in Puerto Rico, as compared to that of the United States, causes the egg size to increase more slowly at the beginning of the laying year, but with the higher summer temperature, egg size decreases faster toward the end of the laying year.

The egg size of the New Hampshires and the White Leghorns was over-all smaller than is commonly seen in similar flocks in the United States. However, it is not clear whether this smaller egg size is a result of a depressive effect of high temperature or is attributable to the breeding of the birds.

Summary

The curve of the egg size (in ounces per dozen eggs) for the first laying year was studied in a group of 206 pullets of different breeds and crossbreds.

Regression studies were made of the average monthly egg size.

The early-maturing pullets started by laying smaller eggs than the late-maturing pullets.

The observations made on the curves of the egg size seems to agree with the findings of Warren et al (9) in respect to the depressive effect of high temperature on egg weight.

Egg size increased progressively during the first months of laying, reaching a maximum from May to June. The high summer temperatures caused it to decrease rapidly toward the end of the laying year.

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COMPARATIVE VALUE OF VARIOUS METHODS OF APPROXIMATING THE PERMANENT WILTING PERCENTAGE

M. A. Lugo López[1]

Introduction

The permanent wilting percentage is of utmost significance in the evaluation of the moisture relationships of soils. Its consideration introduces a biological factor in the classification of soil water. It marks the division between readily available water and water the availability of which is so slight that plants are unable to absorb it at the necessary rate to balance their transpiration requirements. It is generally accepted that the permanent wilting percentage is identical for all plants grown in a given soil. Therefore, it is a soil constant and any differences which may be suggested by plant characteristics are reduced to a negligible minimum. The tenacity with which water is retained in soils when permanent wilting occurs have been fixed at a value of pF 4.2. This is an intermediate position in the moisture range between the hygroscopic coefficient (pF 4.5) and the moisture equivalent (pF 2.7).

Several methods have been proposed to obtain the permanent wilting percentage all of which have certain advantages and also marked shortcomings. The objective of this work was to compare the standard biological method with a purely physical technique and with several indirect approaches.

Materials and Methods

The samples used for this work were those obtained in connection with a more extensive work project on the moisture relationships of Puerto Rican soils (3).[2] Samples were taken from 106 soil types representing the humid and arid regions of the Island. The soils of the humid area were further subdivided into two broad groups, lateritic and nonlateritic. In sampling an area the maps of the Soil Survey of Puerto Rico were used as a guide (7). Composite samples were obtained from the topmost 6 or 8 inches. They were air-dried and passed through a 2-mm. sieve.

The standard biological method was used in determining the permanent wilting percentage (5). Soybean plants were selected as indicator plants because the standard dwarf sunflower was not available at the time the investigation was initiated. In addition, soybeans have been observed to give

[1] Associate Soil Scientist, Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P. R.

[2] Numbers in parentheses refer to Literature Cited, p. 133.

a good indication of the onset of wilting. Four replications were used for each soil. Samples of 46 soil types were submitted to 15 times atmospheric pressure on special plates of the type developed by Richards in California, using a special visking membrane (6). Six replications were used.

The moisture content was determined gravimetrically after the samples reached equilibrium. The values were further compared with those of the permanent wilting percentage as obtained by the biological method. In determining moisture-equivalent values, duplicate determinations were made according to the method outlined by Briggs and McLane by use of a special centrifuge (1). Hygroscopic coefficients were determined by bringing the soil samples to equilibrium with a 3.3-percent solution of sulphuric acid. The clay content was determined by means of sedimentation techniques using the Bouyoucos hydrometer. The Schollenberger colorimetric method was used in determining organic matter. To convert some of the moisture determinations to a volume basis undisturbed cores of soil were taken and oven-dried and their bulk density was calculated. The least-squares method was employed in the statistical interpretation of the data (4).

Experimental Results

The results are all presented in tabular form, and in some cases supplemented by graphs. The experimental data have been organized under two headings: 1, Biological versus purely physical approach, and 2, Indirect approach.

BIOLOGICAL VERSUS PURELY PHYSICAL APPROACH

The biological approach is probably the most widely used and is perhaps the most accurate in hands of a skilled investigator. It is rather simple, the underlying principles are easy to understand, and if due care is exercised in determining the onset of wilting and in following the general procedure, accurate results are likely to be obtained when adequate replications are used. The materials and apparatus used are easily obtained at very low cost. The disadvantage of this approach is that it takes considerable time before results can be obtained. Very often the plants die, causing much delay or decreasing the reliability of the test because of reduction in the number of replicates. Furthermore, the method is completely useless if harmful salt concentrations are present in the soil. It also requires considerable greenhouse space.

Values from 15-atmosphere percentages determined in pressure chambers, as proposed by Richards, were correlated with permanent wilting-percentage values (6). The time required to complete the test is rather short. The greatest handicap of this approach lies in the high initial cost of installation

TABLE 1.—*Relation between the percentage of water by weight remaining in the soil when plants permanently wilt and that remaining after a 15-atmosphere pressure is applied to a saturated soil sample*

Soil type	Sample No.	Permanent wilting percentage	15-atmosphere moisture percentage	Variation
Tiburones muck	94	12.4	15.7	−3.3
Fajardo clay	16	24.0	13.8	+10.2
Mabí clay	21	17.0	18.2	−1.2
Matanzas clay	26	21.6	21.7	− .1
Descalabrado clay	27	18.8	21.4	−2.6
Ponceña clay	31	25.7	36.3	−10.6
Coamo clay	34	17.7	20.8	−3.5
Paso Seco clay	49	18.2	22.8	−4.6
Malaya clay	65	26.6	30.5	−3.9
Vega Baja clay	78	23.5	26.4	−2.9
Ursula clay	96	17.4	22.5	−5.1
Santa Clara clay	107	22.6	30.4	−7.8
San Antón clay	10	24.5	17.9	+6.6
Yunes clay	113	14.9	21.3	−6.4
Rosario clay	118	21.5	23.4	−1.9
Mercedita clay	14	18.6	26.2	−7.6
Moca clay	18	18.2	21.9	−3.7
Espinosa clay loam	25	19.9	21.3	−1.4
Alonso clay loam	48	14.0	15.6	−1.6
Piñones clay loam	53	18.2	19.6	−1.4
Río Cañas clay loam	66	13.6	16.3	−2.7
Maunabo clay loam	81	15.1	17.4	−2.3
Vega Baja clay loam	92	27.5	25.6	+1.9
Sabana Seca sandy clay loam	30	12.0	11.2	− .8
Guayama sandy clay loam	50	14.5	16.1	−1.6
Jayuya sandy clay loam	67	15.1	15.9	− .8
Teresa sandy clay loam	70	18.7	21.3	−2.6
Vives sandy clay loam	74	16.7	17.7	−1.0
Daguao sandy clay loam	84	11.7	12.5	− .8
Palmas Altas sandy clay loam	87	12.6	13.1	− .5
Naranjito sandy clay loam	90	12.3	15.4	−3.1
Múcara sandy clay loam	3	17.8	17.5	+ .3
Guánica silt loam	42	27.3	29.0	−1.7
Maleza fine sandy loam	24	8.8	9.4	− .6
Estación sandy loam	35	11.7	12.2	− .5
Jácana sandy loam	38	13.6	15.0	−1.4
Utuado sandy loam	47	9.7	10.6	− .9
Caguas sandy loam	51	11.0	12.5	−1.5
Vivi sandy loam	54	9.0	11.0	−2.0
Juana Díaz sandy loam	61	10.9	13.0	−2.1
Amelia sandy loam	64	9.8	11.7	−1.9
Irurena sandy loam	86	9.0	8.6	+ .4
San Germán sandy loam	112	24.6	32.9	−8.3
Corozo fine sand	105	1.4	1.4	0
Cataño sand	32	2.5	3.5	−1.0
Dune sand	106	1.2	1.1	+ .1

of the necessary equipment to run such tests. The results obtained compare very favorably as to accuracy with those from more time-consuming methods.

Table 1 gives the results obtained on 46 Puerto Rico soils where permanent wilting-percentage values were determined both by the biological and

the pressure-plate methods. In 37 of the 46 soils, the permanent wilting percentage values lie in the moisture range between the 15-atmosphere percentage and 4-percent moisture above or below it. Examination of the tabular and graphical data indicates that there is rather a good agreement between results obtained by the two techniques (fig. 1).

A correlation coefficient of 0.90 was obtained between the two methods. It is very high indeed. A functional relationship was established and the

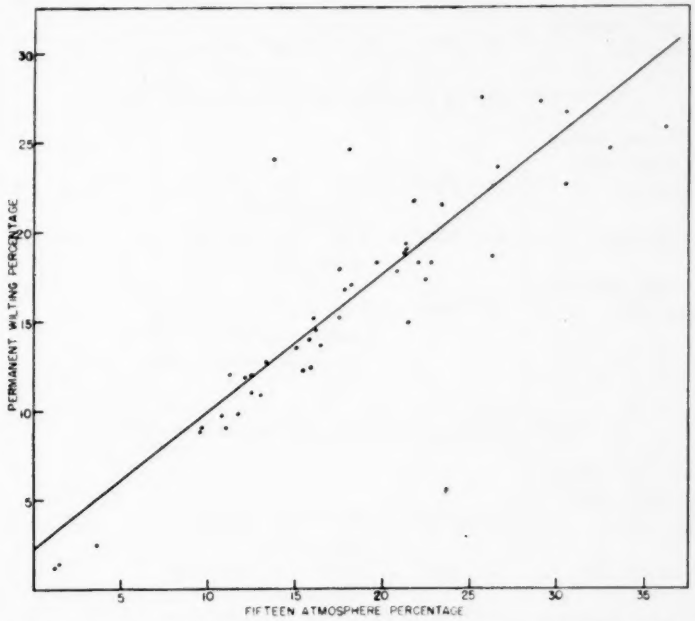

FIG. 1.—Relationship between permanent wilting percentage and 15-atmosphere percentage.

following equation obtained for estimation of accurate permanent wilting percentages on basis of pressure plate data:

$$PWP = 2.37 + 0.76\,X,$$

where X is the amount of moisture remaining in a soil after submitting a saturated sample to a 15-atmosphere pressure.

INDIRECT APPROACH

Numerous investigators have proposed the estimation of permanent wilting-percentage values in terms of other more easily determined soil constants. The work of Briggs and Shantz on this is well known (2).

TABLE 2.—*Relation of the permanent wilting percentage to clay content, organic-matter content, moisture equivalent, and hygroscopic coefficient in the soils of Puerto Rico*

Soil group	Samples	Functional relationship	Coefficient of determination	Correlation coefficient
		Permanent wilting percentage and clay content		
	Number			
Humid- and subhumid-region soils				
Lateritic	19	PWP = 5.80 + 0.53 (percent clay)	0.80	+0.89
Nonlateritic	52	PWP = 3.28 + .53 (percent clay)	.76	+ .87
Arid- and semiarid-region soils	34	PWP = 13.85 + .25 (percent clay)	.31	+ .55
		Permanent wilting percentage and organic-matter content		
Humid- and subhumid-region soils				
Lateritic	19	PWP = 4.33 + 6.80 (percent organic matter)	0.44	+0.66
Nonlateritic	48	PWP = 7.25 + 3.93 (percent organic matter)	.29	+ .54
Arid- and semiarid-region soils	32	PWP = 11.96 + 5.75 (percent organic matter) −0.88 (percent organic matter)	.07	+ .27
		Permanent wilting percentage and moisture equivalent		
Humid- and subhumid-region soils				
Lateritic	19	PWP = 2.75 + 0.73 (moisture equivalent)	0.35	+0.59
Nonlateritic	52	PWP = 2.16 + .56 (moisture equivalent)	.44	+ .66
Arid- and semiarid-region soils	34	PWP = 1.75 + .58 (moisture equivalent)	.53	+ .73
		Permanent wilting percentage and hygroscopic equivalent		
Humid- and subhumid-region soils				
Lateritic	19	PWP = 4.49 + 1.11 (hygroscopic coefficient)	0.83	+0.90
Nonlateritic	52	PWP = 1.46 + 1.21 (hygroscopic coefficient)	.73	+ .85
Arid- and semiarid-region soils	34	PWP = 5.25 + .98 (hygroscopic coefficient)	.74	+ .85
Puerto Rico, all soils	105	PWP = 2.84 + 1.14 (hygroscopic coefficient)	0.76	+0.87

Table 2 gives regression equations to estimate permanent wilting percentages on a basis of the clay and organic-matter content, respectively, of three groups of soils. The correlation between permanent wilting percentage and clay content is very good for humid-region soils, both lateritic and nonlateritic, but is unsatisfactory for soils of the arid areas. As far as organic matter is concerned no good correlation was obtained, except perhaps a fairly acceptable one for lateritic soils.

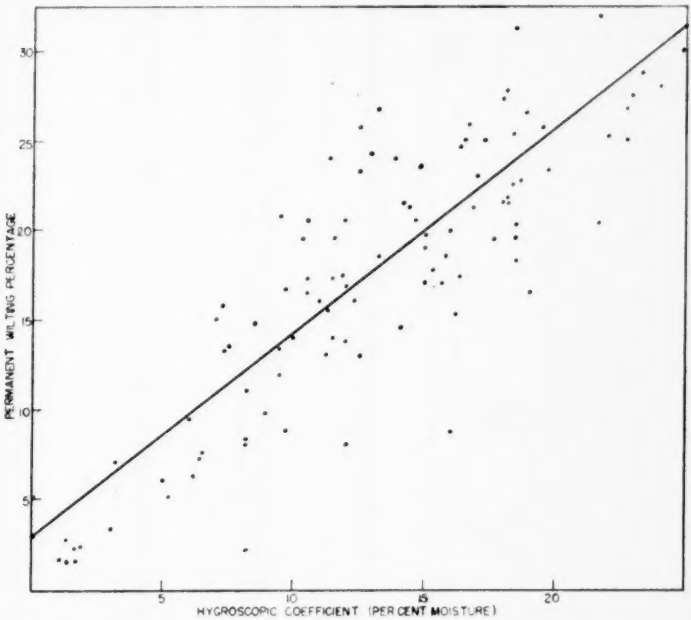

FIG. 2.—Relationship between permanent wilting percentage and hygroscopic coefficient.

Further correlations were attempted between permanent wilting percentage and other soil physical constants. Table 2 also shows the functional relationships established between permanent wilting percentage and moisture equivalent. The correlation is more satisfactory for soils of the arid and semiarid regions than for those of humid regions. For both arid- and humid-region soils there was a better correlation than that obtained between permanent wilting percentage and organic-matter content. The correlation between permanent wilting percentage and hygroscopic coefficient is very highly satisfactory in all cases (table 2) (fig. 2). Coefficients of correlation are high and errors of estimate are at a minimum.

TABLE 3.—*Relation of the permanent wilting percentage of various Puerto Rican soil types as determined by the biological method to the permanent wilting percentage as calculated from the 15-atmosphere moisture percentage*

Soil type	Sample No.	Permanent wilting percentage by the biological method	15-atmosphere moisture percentage	Calculated permanent wilting percentage[1]
Tiburones muck	94	12.4	15.7	14.3
Fajardo clay	16	24.0	13.8	12.9
Mabí clay	21	17.0	18.2	16.2
Matanzas clay	26	21.6	21.7	18.9
Descalabrado clay	27	18.8	21.4	18.7
Ponceña clay	31	25.7	36.3	30.0
Coamo clay	34	17.7	20.8	18.2
Paso Seco clay	49	18.2	22.8	19.7
Malaya clay	65	26.6	30.5	25.6
Vega Baja clay	78	23.5	26.4	22.5
Ursula clay	96	17.4	22.5	19.5
Santa Clara clay	107	22.6	30.4	25.5
San Anton clay	10	24.5	17.9	16.0
Yunes clay	113	14.9	21.3	18.6
Rosario clay	118	21.5	23.4	20.2
Mercedita clay	14	18.6	26.2	22.3
Moca clay	18	18.2	21.9	19.0
Espinosa clay loam	25	19.9	21.3	18.6
Alonso clay loam	48	14.0	15.6	14.2
Piñones clay loam	53	18.2	19.6	17.3
Río Cañas clay loam	66	13.6	16.3	14.8
Maunabo clay loam	81	15.1	17.4	15.6
Vega Baja clay loam	92	27.5	25.6	21.9
Sabana Seca sandy clay loam	30	12.0	11.2	10.9
Guayama sandy clay loam	50	14.5	16.1	14.6
Jayuya sandy clay loam	67	15.1	15.9	14.5
Teresa sandy clay loam	70	18.7	21.3	18.6
Vives sandy clay loam	74	16.7	17.7	15.9
Daguao sandy clay loam	84	11.7	12.5	11.9
Palmas Altas sandy clay loam	87	12.6	13.1	12.4
Naranjito sandy clay loam	90	12.3	15.4	14.1
Múcara sandy clay loam	3	17.8	17.5	15.7
Guánica silt loam	42	27.3	29.0	24.5
Maleza fine sandy loam	24	8.8	9.4	9.5
Estación sandy loam	35	11.7	12.2	11.7
Jácana sandy loam	38	13.6	15.0	13.8
Utuado sandy loam	47	9.7	10.6	10.4
Caguas sandy loam	51	11.0	12.5	11.9
Viví sandy loam	54	9.0	11.0	10.7
Juana Díaz sandy loam	61	10.9	13.0	12.3
Amelia sandy loam	64	9.8	11.7	11.3
Irurena sandy loam	86	9.0	8.6	8.9
San Germán sandy loam	112	24.6	32.9	27.4
Corozo fine sand	105	1.4	1.4	3.4
Cataño sand	32	2.5	3.5	5.0
Dune sand	106	1.2	1.1	3.2

[1] Calculated from the equation: PWP = 2.37 + 0.76 X, where X is the 15-atmosphere-moisture percentage.

DISCUSSION OF RESULTS

A comparison of permanent wilting-percentage values obtained directly by biological methods with 15-atmosphere-percentage values obtained in

TABLE 4.—*Relation of the permanent wilting percentage of various Puerto Rican soil types as determined by the biological method to the permanent wilting percentage as calculated from the hygroscopic coefficient*

Soil type	Sample No.	Permanent wilting percentage by the biological method	Hygroscopic coefficient (percent moisture)	Calculated permanent wilting percentage[1]
Nipe clay	8	30.1	21.2	27.0
Rosario clay	118	21.5	20.3	25.9
Catalina clay	4	28.1	18.7	24.2
Cialitos clay	6	30.4	25.1	31.5
Matanzas clay	26	25.2	22.0	27.9
Lajas clay	45	26.7	13.2	17.9
Tanamá clay	58	25.8	16.4	21.6
Malaya clay	65	32.1	21.6	27.4
Río Piedras clay	114	26.6	20.0	24.6
Lares clay	1	28.9	23.4	29.5
Coloso clay	2	23.4	14.7	19.6
Fajardo clay	16	25.1	22.7	28.8
Moca clay	18	22.5	18.3	23.7
Mabí clay	21	19.4	17.7	22.9
Cabo Rojo clay	44	23.1	17.1	22.3
Colinas clay	59	25.8	12.6	17.2
Plata clay	62	20.6	11.8	16.3
Soller clay	76	32.9	16.6	21.7
Fortuna clay	77	24.9	17.2	22.4
Vega Baja clay	78	25.8	19.4	25.0
Yabucoa clay	88	14.0	11.4	15.9
Santa Clara clay	107	22.6	18.6	24.0
Yunes clay	113	14.9	8.4	12.4
Fraternidad clay	9	22.0	21.3	27.2
San Antón clay	10	27.9	24.3	30.6
Mercedita clay	14	25.3	18.4	23.8
Descalabrado clay	27	25.0	22.9	28.9
Ponceña clay	31	39.2	27.4	34.1
Reparada clay	33	25.0	16.5	21.6
Coamo clay	34	21.4	18.0	23.3
Fe clay	36	21.9	18.2	23.6
Vayas clay	37	20.3	13.2	17.8
Paso Seco clay	49	21.5	18.2	23.5
Portugués clay	60	21.1	16.8	22.0
Aguirre clay	63	18.6	18.6	24.1
Ursula clay	96	17.4	15.8	20.9
Espinosa clay loam	25	26.7	22.7	28.7
Alonso clay loam	48	17.2	11.2	15.6
Vega Alta clay loam	92	24.2	12.9	17.5
Córcega clay loam	19	17.4	11.8	16.3
Toa clay loam	28	18.9	15.1	20.0
Piñones clay loam	53	20.1	15.9	20.9

TABLE 4.—*Continued*

Soil type	Sample No.	Permanent wilting percentage by the biological method	Hygroscopic coefficient (percent moisture)	Calculated permanent wilting percentage[1]
Camagüey clay loam	75	23.9	11.3	15.7
Los Guineos clay loam	79	13.1	7.5	11.4
Maunabo clay loam	81	19.5	10.3	14.6
Juncos clay loam	95	16.6	18.5	23.9
Sabana clay loam	100	15.3	16.1	21.2
Aguilita clay loam	15	17.6	15.2	20.1
Yauco clay loam	29	19.6	18.5	23.9
Santa Isabel clay loam	39	23.4	19.8	25.3
Pozo Blanco clay loam	41	21.7	14.2	19.0
Río Cañas clay loam	66	19.9	14.2	19.0
Coto sandy clay loam	12	17.3	10.7	15.1
Múcara sandy clay loam	3	21.2	14.4	19.3
Sabana Seca sandy clay loam	30	17.4	16.4	21.5
Jayuya sandy clay loam	67	20.6	10.7	15.0
Daguao sandy clay loam	84	15.7	7.2	11.1
Palmas Altas sandy clay loam	87	16.0	12.3	16.9
Las Piedras sandy clay loam	89	17.1	14.9	19.8
Naranjito sandy clay loam	90	13.9	11.8	16.2
Vía sandy clay loam	97	9.7	8.9	12.9
Martín Peña sandy clay loam	104	19.7	14.9	19.8
Teresa sandy clay loam	70	23.9	13.8	18.6
Vives sandy clay loam	74	23.8	12.5	17.1
Picacho silt loam	110	12.0	9.6	13.7
Cintrona silt loam	40	18.5	13.4	18.1
Guánica silt loam	42	27.1	17.8	23.1
Serrano silt loam	68	17.2	15.6	20.6
Torres loam	91	16.7	9.7	13.9
Barrancas loam	72	19.5	11.5	15.9
Almirante fine sandy loam	17	6.9	3.1	6.3
Maleza fine sandy loam	24	12.9	12.5	17.1
Bayamón fine sandy loam	93	20.6	9.4	13.5
Caguas sandy loam	51	14.1	9.9	14.2
Estación sandy loam	35	15.2	14.0	18.8
Utuado sandy loam	47	13.1	11.3	15.7
Viví sandy loam	54	11.0	12.9	17.6
Humacao sandy loam	55	16.4	10.7	15.1
Ciales sandy loam	56	15.4	11.3	15.7
Josefa sandy loam	82	11.0	8.3	12.3
Irurena sandy loam	86	13.5	9.3	13.4
Pandura sandy loam	98	8.0	8.3	12.3
Cayaguá sandy loam	99	6.2	6.0	9.7
Talante sandy loam	101	8.7	9.6	13.8
Teja sandy loam	102	6.9	6.3	10.0
Candelero sandy loam	103	8.3	8.3	12.2

TABLE 4.—*Concluded*

Soil type	Sample No.	Permanent wilting percentage by the biological method	Hygroscopic coefficient (percent moisture)	Calculated permanent wilting percentage[1]
Jácana sandy loam	38	15.9	10.9	15.2
Guayama sandy loam	50	16.7	11.9	16.4
Juana Díaz sandy loam	61	16.0	8.9	13.0
Amelia sandy loam	64	12.4	8.0	12.0
Machete sandy loam	71	13.6	7.4	11.3
Altura sandy loam	73	15.3	6.9	10.8
San Germán sandy loam	112	24.5	16.2	21.4
Ensenada sandy loam	115	20.2	18.8	24.3
Algarrobo fine sand	7	5.1	5.1	8.7
St. Lucie fine sand	11	2.1	1.6	4.6
Guayabo fine sand	23	2.0	1.4	4.5
Corozo fine sand	105	1.5	1.4	4.5
Islote sand	20	9.5	6.0	9.7
Aguadilla sand	22	7.5	6.2	9.8
Cataño sand	32	3.4	2.9	6.1
Dune sand	106	1.2	1.1	4.1
Meros sand	69	6.0	5.1	8.6
Río Lajas sand	80	1.6	1.0	4.0
Jaucas sand	116	2.6	1.4	4.4

[1] Calculated from the equation: $PWP = 2.84 + 1.14\,X$, where X is the hygroscopic coefficient.

pressure chambers shows that the latter can be used with reliability to indicate the water remaining in the soil when the plants permanently wilt (table 3). Moreover, predictions of these values can be ascertained with reasonable accuracy by use of regression equations based on the hygroscopic coefficient (table 4). In determining hygroscopic coefficients for soils it usually takes three or more weeks before the samples attain equilibrium with the special environment in which they must be placed. However, the determination requires less work, much smaller samples, and not as much space as the direct biological determination. Besides, no large initial expenditures are involved as compared with the method in which pressure plates are used. Of course, the hygroscopic-coefficient method is not as accurate as the other.

A very high correlation such as the one obtained between the 15-atmosphere percentage and the permanent wilting percentage determined by the biological method is observed only with the lateritic group of soils using the indirect determination with the hygroscopic coefficient as the independent factor. Nevertheless the correlation is high enough in all cases to indicate that the approach based on the hygroscopic coefficients is acceptable where

precise measurements are not required or when the equipment needed for more accurate work is not available.

The indirect approach of estimating permanent wilting-percentage values on a basis of the clay content seems to be reliable for soils of the humid areas. In such cases it is recommended because of the rapidity with which clay contents can be approximated by use of the hydrometer technique. Regression equations using organic-matter content to estimate permanent wilting-percentage values are not to be relied upon, except perhaps when dealing with lateritic soils. Where feasible, 15-atmosphere percentages are to be preferred not only for their accuracy but for the speed with which results can be obtained.

Summary

Very accurate estimations of the permanent wilting percentage can be obtained for soils of all regions of Puerto Rico by use of regression equations based on the hygroscopic coefficient. Reliable estimates can also be obtained for humid-region soils by using the clay content as a basis. Attempts to correlate permanent wilting-percentage values with moisture equivalents and organic-matter content did not give such satisfactory results. The 15-atmosphere percentage as determined by using pressure plates gives an accurate approximation of permanent wilting-percentage values. It is time-saving, but initial expense in laboratory equipment is rather high. This approach is to be preferred whenever feasible. A regression equation is given relating pressure-plate values to the permanent wilting percentage. Whenever less precise estimates are acceptable and time is not a factor, advantage should be taken of the established correlation between the hygroscopic coefficient and the permanent wilting percentage.

Resumen

Mediante ecuaciones de regresión, basadas en el coeficiente de higroscopicidad, se puede predecir con bastante exactitud el punto de marchitez permanente en suelos de diversas regiones de Puerto Rico. El contenido de arcilla de los suelos de regiones húmedas puede también servir como base para hacer predicciones bastante aceptables de dicha constante. Las tentativas para establecer predicciones, a base del equivalente de humedad y del contenido de materia orgánica, no dieron resultados tan satisfactorios. La determinación de la humedad en muestras sometidas a una presión de 15 atmósferas en cámaras especiales, da una idea bastante exacta del punto de marchitez permanente. La determinación toma poco tiempo, pero el costo inicial del equipo de laboratorio necesario es alto. Siempre que sea posible, se debe preferir este método para aproximar los valores del punto de marchitez permanente. Se presenta una ecuación de regresión relacio-

nando los valores obtenidos en dichas cámaras con los obtenidos por el método biológico. Se recomienda aprovecharse de la relación entre el coeficiente de higroscopicidad y el punto de marchitez permanente, siempre que no precise mucha exactitud y cuando el tiempo no sea un factor limitante.

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AVAILABLE WATER CAPACITY OF THE SURFACE LAYER OF VARIOUS SOILS FROM THE ARID AND SEMIARID REGION OF PUERTO RICO

M. A. Lugo-López[1]

Introduction

Soil moisture is the most important single factor affecting the yields of crops in southern Puerto Rico. In ordinary years no profitable crop growth can be expected without irrigation. The amount of water that a soil can hold in a state of ready availability for crops varies with the soil type. It is generally accepted that clayey soils usually hold more total water than sandy ones, but it is not so well recognized that some sandy soils may hold as much available water for plants as do heavier types. Of course, the value of soils, particularly in regions where irrigation is necessary, depends not on their total water-holding-capacity, but on how much usable water they can store. If plants cannot avail themselves of the water present, there is no definite advantage in high water-holding-capacity soils. The water that plants find in readily available form is what really matters.

Materials and Methods

Samples of 34 soils from the arid and semiarid regions were collected including several from the Lajas Valley in southwestern Puerto Rico (table 1). The maps of the Soil Survey of Puerto Rico were used as a guide (7)[2] in sampling an area. Composite samples were taken from the topmost 8 inches following the technique of Cline (2); then they were air-dried, thoroughly mixed, and passed through a 2-mm. sieve. Special undisturbed samples were taken for bulk-density measurements by using a Bradfield-type cylinder.

All moisture determinations were calculated on the dry-weight basis and later converted to the volume basis by using density values. Field-capacity determinations were made for each soil by packing two soil columns in 2-l. cylinders, wetting them as suggested by Weaver and Clements, and drying duplicate samples from each cylinder in an oven at 105° C. (9). The plant method was used in determining the permanent wilting percentage, using soybeans as indicator plants with four replications for each soil. The 15-atmosphere-moisture percentage was obtained by submitting six samples from each soil in special plates to a pressure of 225 pounds per square inch

[1] Associate Soil Scientist, Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P. R.

[2] Numerals in parentheses refer to Literature Cited, p. 140.

as proposed by Richards and Weaver (6). The moisture equivalent was determined from duplicate samples according to the method of Briggs and

TABLE 1.—*Approximate location of the soil samples used in this study*

Soil type	Sample No.	Location
Fraternidad clay	9	Km. 229 H. 4, Road No. 2
San Antón clay	10	Km. 1, Variante (near Ponce)
Mercedita clay	14	Near Central Mercedita, East of Ponce
Descalabrado clay	27	Km. 169 H. 9, Road No. 2, between Añasco and Rincón
Ponceña clay	31	Km. 125, road from Juana Díaz to Ponce
Reparada clay	33	Road No. 2, East of Guayanilla
Coamo clay	34	Km. 120 H. 8, Road No. 1
Fe clay	36	Outskirts of Ponce; road to Juana Díaz
Vayas clay	37	Road No. 2, near M. Mercado's residence
Paso Seco clay	49	Hacienda Desengaño, Lajas Valley
Portugués clay	60	Road from Ponce to Juana Díaz, Hacienda Barrancas
Aguirre clay	63	Hacienda Desengaño, Lajas Valley
Ursula clay	96	Pastillo (Ponce-Juana Díaz)
Aguilita clay loam	15	Near M. Mercado's residence, Guayanilla-Ponce
Yauco clay loam	29	Km. 236, Road No. 2
Santa Isabel clay loam	39	Km. 215 H. 5, Road No. 2
Pozo Blanco clay loam	41	Km. 7 H. 8, road to Lajas
Río Cañas clay loam	66	Hacienda Algarrobo, Road Guayama to Patillas
Teresa sandy clay loam	70	Entrance to Central Cortada
Vives sandy clay loam	74	Hacienda Algarrobo, after Central Lafayette, road Arroyo-Guayama
Cintrona silt loam	40	Near Playa de Ponce
Guánica silt loam	42	Near Lake Cartagena, Lajas Valley
Serrano silt loam	68	Pastillo, Km. 185 H. 6, Ponce
Barrancas loam	72	Hacienda Ponceña, near dam
Jácana sandy loam	38	Km. 212 H. 9, Road No. 2
Guayama sandy loam	50	Barrio Guanábana, Lajas Valley
Juana Díaz sandy loam	61	Road No. 1, after Juana Díaz
Amelia sandy loam	64	Near Lake Cartagena, Lajas Valley
Machete sandy loam	71	Central Machete
Altura sandy loam	73	Near Hacienda Altura, Km. 160 H. 2, Road No. 1
San Germán sandy loam	112	Km. 225 H. 4, Sabana Grande-Yauco
Ensenada sandy loam	115	Near lighthouse, Morrillos de Cabo Rojo
Meros sand	69	Between Santa Isabel and Salinas
Jaucas sand	116	Near lighthouse, Morrillos de Cabo Rojo

McLane (1). Bulk-density determinations were made by drying the undisturbed cores of known volume in an oven at 105° C.

Presentation of Data and Discussion

The available water in soils is regarded as the moisture held at tensions between those of field capacity (about pF 2.0 to 3.0) and permanent wilting percentage (pF 4.2). Field capacity as defined by Veihmeyer and Hendrickson (8) indicates "the amount of water held in the soil after the rate of downward movement of water has materially decreased." In well-drained soils this condition may occur ordinarily 2 or 3 days after they have been thoroughly wet. Laboratory procedures for determining this soil constant are inconvenient and not very precise. The possibility of using other soil constants which can be determined more easily and accurately has been suggested by several workers. Attempts to predict field-capacity values of humid-region soils from Puerto Rico on a basis of clay percentages were successful, but failed when dealing with arid- and semiarid-region soils (3).

Table 2.—*Relation between moisture equivalent and field capacity in selected soil types from the arid and semiarid regions of Puerto Rico*

Soil type	Moisture equivalent (percent water)	Field capacity (percent water)	Variation
Mercedita clay	42.8	44.6	+1.8
Descalabrado clay	43.7	40.4	−3.3
Paso Seco clay	42.8	42.7	− .1
Aguirre clay	35.6	38.8	+3.2
Ursula clay	40.0	40.7	+ .7
Santa Isabel clay loam	46.7	46.6	− .1
Pozo Blanco clay loam	37.0	39.5	+2.5
Río Cañas clay loam	40.8	42.6	+1.8
Vives sandy clay loam	43.9	40.6	−3.3
Barrancas loam	42.0	41.8	− .2

Other investigators have presented data relating moisture equivalents to field capacities for South Carolina soils (5).

Moisture equivalents can be obtained easily and accurately under controlled laboratory conditions. An attempt to obtain a reliable regression of field capacity on moisture equivalent in order to evolve an equation to predict the former soil constant in terms of the latter was not successful with soils of arid and semiarid Puerto Rico. For certain individual soils, however, moisture equivalents can be used as a measure of field capacities. Table 2 shows the variation between field-capacity and moisture-equivalent values for several soil series. The field capacity ranges from nearly 39 per cent in Aguirre clay to 46.6 per cent in Santa Isabel clay loam and the moisture-equivalent range is from 35.6 to 46.7 in the same soils. The values agree rather closely, the field capacity deviating less than 4 percent above or below the moisture equivalent.

The permanent wilting percentage is regarded as the moisture content below which plants are unable to obtain water readily enough to offset transpiration losses. It can be obtained accurately by determining the water which remains in the soil when wilting occurs. However, this method requires much labor and usually takes 2 or 3 weeks to complete. Attempts to correlate permanent wilting percentages with other soil constants have been made (4). The regression of permanent wilting percentage on 15-atmosphere percentage for Puerto Rican soils has been expressed by the equation, $Y = 2.37 + 0.76\ X$, in which Y is the permanent wilting percentage and X is the 15-atmosphere percentage. A correlation coefficient of 0.90 indicates that the values are very closely associated. Table 3 shows the relation between permanent wilting percentage and 15-atmosphere percentage in 12 soils from the arid and semiarid region. In general, the permanent wilting percentage lies in the range between the 15-atmosphere percentage and 5-percent moisture below it.

TABLE 3.—*Relation between permanent wilting percentage and 15-atmosphere percentage in selected soil types from the arid and semiarid regions of Puerto Rico*

Soil type	Permanent wilting percentage	15-atmosphere moisture percentage	Variation
Descalabrado clay	18.8	21.4	−2.6
Coamo clay	17.7	20.8	−3.5
Paso Seco clay	18.2	22.8	−4.6
Ursula clay	17.4	22.5	−5.1
Río Cañas clay loam	13.6	16.3	−2.7
Guayama sandy clay loam	14.5	16.1	−1.6
Teresa sandy clay loam	18.7	21.3	−2.6
Vives sandy clay loam	16.7	17.7	−1.0
Guánica silt loam	27.3	29.0	−1.7
Jácana sandy loam	13.6	15.0	−1.4
Juana Díaz sandy loam	10.9	13.0	−2.1
Amelia sandy loam	9.8	11.7	−1.9

The available water content for a number of soils in southern and southwestern Puerto Rico is shown in table 4. In clay soils the values range from about 18 to 25 percent. Clay loams fluctuate from 17.6 to 21.6, silt loams from 17.7 to nearly 25, sandy loams and sandy clay loams from 18.6 to 24, and sands from 9 to 16.7. The tendency is for heavier soils to have higher water-holding capacities, but their permanent wilting percentages are correspondingly higher. On the other hand, on lighter soils where field-capacity values are lower, permanent wilting occurs at lower moisture contents. Some sandy soils hold as much as or even more available water

than heavier clayey soils. Jácana sandy loam, for example, can store about 22 percent of available water in its surface layer, while Aguirre clay can

TABLE 4.—*Field capacity, permanent wilting percentage, and available water capacity of the surface layer of 34 representative soils from the arid and semiarid regions of Puerto Rico*

Soil type	Sample No.	Field capacity (percent water)	Permanent wilting percentage	Available water capacity (percent water)
Fraternidad clay	9	45.3	22.0	25.3
San Antón clay	10	48.7	27.9	20.8
Mercedita clay	14	42.8	25.3	17.5
Descalabrado clay	27	42.9	25.0	17.9
Ponceña clay	31	59.4	39.2	20.2
Reparada clay	33	46.8	25.0	21.8
Coamo clay	34	42.4	21.4	21.0
Fe clay	36	42.6	21.9	20.7
Vayas clay	37	35.6	20.3	15.3
Paso Seco clay	49	43.6	21.5	22.1
Portugués clay	60	39.7	21.1	18.6
Aguirre clay	63	36.7	18.6	18.1
Ursula clay	96	40.4	17.4	23.0
Aguilita clay loam	15	35.2	17.6	17.6
Yauco clay loam	29	39.6	19.6	20.0
Santa Isabel clay loam	39	45.0	23.4	21.6
Pozo Blanco clay loam	41	42.6	21.7	20.9
Río Cañas clay loam	66	39.1	20.0	19.1
Teresa sandy clay loam	70	42.5	23.9	18.6
Vives sandy clay loam	74	46.9	23.8	23.1
Cintrona silt loam	40	43.1	18.5	24.6
Guánica silt loam	42	44.8	27.1	17.7
Serrano silt loam	68	42.0	17.1	24.9
Barrancas loam	72	39.0	19.5	19.5
Jácana sandy loam	38	37.4	15.6	21.8
Guayama sandy loam	50	40.6	16.7	23.9
Juana Díaz sandy loam	61	40.0	16.0	24.0
Amelia sandy loam	64	31.5	12.4	19.1
Machete sandy loam	71	32.4	13.6	18.8
Altura sandy loam	73	36.0	15.3	20.7
San Germán sandy loam	112	46.0	24.6	21.4
Ensenada sandy loam	115	43.9	20.2	23.7
Meros sand	69	15.0	6.0	9.0
Jaucas sand	116	19.3	2.6	16.7

only store 18.1. Juana Díaz sandy loam and Ensenada sandy loam can store 24 and 23.7 percent, respectively, while Vayas clay and Mercedita clay only store 15.3 and 17.5 percent, respectively (table 4).

From the moisture viewpoint soils must be judged according to their range of available moisture content. In these respect many light-textured soils can be rated as good or better than heavier ones. Most of the soils from the arid and semiarid regions of Puerto Rico have on their surface layer an adequate range of available water. However, the application of irrigation waters must be carefully gaged to conform with their ability to store available water in the root zone. Otherwise heavy losses are likely to occur.

Summary

The available water of soils is considered to be in the moisture range from field capacity to permanent wilting percentage. The customary procedures for determining these two soil constants are quite inconvenient. Although data are presented that show good agreement between moisture equivalents and field-capacity values in selected soils, it was not possible to obtain a reliable regression with soils from the arid and semiarid regions of Puerto Rico. The regression of permanent wilting percentages by the plant method to 15-atmosphere percentages is expressed by the equation, $Y = 2.37 + 0.76\ X$, in which Y is the permanent wilting percentage and X is the 15-atmosphere percentage. Data on the available water capacity of the surface layer of soils from the arid and semiarid regions of Puerto Rico are presented. The range of available water is adequate in most soils, fluctuating from about 18 to 25, except in sands where it is lower. It is about the same in heavy soils such as clays and clay loams as in lighter ones such as sandy loam and sandy clay loams.

Resumen

El agua aprovechable de los suelos es la que se encuentra retenida entre la capacidad de campo y el punto de marchitez permanente. Las técnicas para determinar estas dos constantes son muy inconvenientes. Aunque se presentan datos que demuestran la relación entre los valores del equivalente de humedad y la capacidad de campo de algunos suelos de las regiones áridas y semiáridas de Puerto Rico, no se pudo obtener una regresión válida. La regresión entre el punto de marchitez permanente y el contenido de humedad en las muestras de suelo sometidas a una presión de 15-atmósferas se puede expresar por medio de la ecuación: $Y = 2.37 + 0.76\ X$, donde Y representa el punto de marchitez permanente y X el porciento de humedad restante en las muestras sometidas a una presión de 15-atmósferas. Se presentan aquí datos sobre la capacidad de retención del los agua aprovechable de los suelos de las zonas áridas y semiáridas de Puerto Rico. La mayoría de los suelos tienen una capacidad adecuada que fluctúa entre 18 y 25 porciento, excepto en las arenas donde es menor. Dicha capacidad

es casi idétnica en los suelos pesados, tales como arcillas y arcillas lómicas y en los suelos livianos, tales como los lómico arenosos y las arcillas arenoso lómicas.

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TRACING THE MINERAL FROM THE SOIL TO THE PLANT

PART V. EFFECT OF LIME AND PHOSPHORUS ON GUINEA, MERKER, AND PARA-CARIB GRASSES GROWN IN ASSOCIATION WITH TROPICAL KUDZU[1]

J. A. Bonnet, A. R. Riera, and J. Roldán[2]

Introduction

The effect of lime and phosphorus on the available calcium, magnesium, manganese, phosphorus, and iron contents of the acid red soil, Fajardo clay, and on the quantities of those elements present, and the yield in various cuttings of Para-Carib grass, was studied from 1943 to 1946 and reported by Bonnet and Riera (1, 2).[3]

This paper presents the data obtained in similar studies, made from 1948 to 1950, with Guinea grass *Panicum maximum* and Merker grass *Pennisetum purpureum* grown alone, and of these grasses and a mixture of Para-grass *Panicum purpurascens* and Carib grass *Eriochloa Polystachya*, grown in association with tropical kudzu *Pueraria phaseoloides*.

Experimental Work

After the final Para-Carib grass cutting was harvested, in the first set of experiments (1, 2), the corresponding thirty-six $^2/_{10}$-acre plots were plowed separately. The soil reaction of the previously limed plots of Fajardo clay was found to vary from pH 4.4 to 5.1, and limestone was applied again on March 9, 1948, at rates varying from 0.5 to 4.5 tons per acre to raise the soil reaction to about pH 6.5. The soil reaction of the unlimed plots varied from pH 4.2 to pH 5.0.

A part of some of the plots that had undergone the previous four treatments: Check, calcium, phosphorus, and calcium-phosphorus, was subdivided into five $^1/_{100}$-acre plots for the following subtreatments: Guinea grass, Merker grass, Guinea-kudzu, Merker-kudzu, and Para-Carib-kudzu. The experiment covered a total of 120 $^1/_{100}$-acre plots consisting of six replications, four fertilizer treatments, and five grass subtreatments.

Seeds of kudzu, scarified with sulfuric acid, 1:1 solution, were planted on May 4, 1948 in the corresponding plots. The respective grasses were planted 3 months later. Each of the grass-kudzu plots had three kudzu and four

[1] This is Part V of the studies hitherto published under the general title: "Tracing the Mineral from the Soil to the Plant to the Animal Blood."

[2] Soil Chemist, Head Soils Department; Associate Chemist, and Research Assistant in Chemistry, respectively, Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P. R.

[3] Numbers in parentheses refer to Literature Cited, p. 154.

grass rows, spaced at 1.5 feet between rows. The grass plots had four rows of grasses, spaced 3 feet apart.
grass rows, planted with 1.5 feet between rows. The grass plots had four rows of grasses, spaced 3 feet apart.

Phosphorus was applied as a superphosphate to the corresponding plots on July 30, 1948, at the rate of 100 pounds of P_2O_5 to the acre.

The consecutive six grass and grass-kudzu cuttings were harvested around October 13, 1948; January 26, May 24, September 1, and November 30, 1949, and April 19, 1950, respectively. The first and third cuttings each

FIG. 1.—Guinea grass grown in association with kudzu; second cutting, 104 days old.

received an application of 50 pounds NH_3 to the acre, the first as ammonium sulfate and the third as ammonium nitrate.

Figures 1 to 3 show pictures of the various grasses growing in association with tropical kudzu.

PRESENTATION AND DISCUSSION OF THE DATA

YIELDS

The age, season, and yields of dry grass and grass-kudzu per cutting and per treatment are reported in table 1. The crop mean for each of the six cuttings of dry Guinea grass varied from 1.37 to 4.47 tons per acre; for dry Merker grass from 2.82 to 5.66 tons per acre; for the dry Guinea-kudzu

FIG. 2.—Merker grass grown in association with kudzu; second cutting, 104 days old. Observe how the kudzu climbs the stems of the grass.

FIG. 3.—Para-Carib grass grown in association with kudzu; second cutting, 104 days old.

TABLE 1.—*Age, season, and yields of 6 cuttings of dry grass and grass-kudzu, in tons per acre, as related to treatments*

Cutting	Season	Crop age (days)	Symbol[1]	Check	Ca	P	CaP	Crop mean
1	Fall	70[2]	G	3.00	2.67	2.38	2.87	2.73
			M	3.13	3.67	3.13	3.80	3.43
			GK	3.47	3.53	3.20	3.49	3.43
			MK	3.68	4.28	3.36	4.53	3.97
			PK	3.08	3.44	2.88	3.54	3.24
			Treatment mean	3.26	3.52	2.99	3.65	3.36
2	Winter	104	G	1.82	1.97	1.69	2.00	1.87
			M	2.43	3.28	2.52	3.58	2.95
			GK	2.78	3.15	3.12	3.42	3.12
			MK	3.75	5.30	3.29	6.26	4.65
			PK	2.45	3.03	3.03	3.54	3.01
			Treatment mean	2.64	3.35	2.73	3.76	3.12
3	Spring	119	G	2.96	3.27	2.52	3.07	2.96
			M	2.61	3.85	3.02	4.04	3.38
			GK	4.07	4.21	4.30	4.02	4.15
			MK	4.83	5.09	4.46	4.86	5.04
			PK	2.91	2.47	3.18	3.43	3.00
			Treatment mean	3.48	3.78	3.50	4.06	3.71
4	Summer	99	G	4.23	4.84	4.16	4.66	4.47
			M	4.45	6.57	5.03	6.60	5.66
			GK	5.07	5.47	5.64	5.34	5.38
			MK	5.54	6.91	5.81	7.35	6.40
			PK	3.76	3.82	4.04	4.17	3.95
			Treatment mean	4.61	5.52	4.94	5.61	5.17
5	Fall	62	G	2.23	2.64	1.78	2.14	2.20
			M	3.09	3.53	2.54	3.68	3.21
			GK	2.62	3.05	2.62	2.85	2.78
			MK	3.79	4.38	3.51	4.30	4.00
			PK	2.21	2.31	2.10	2.46	2.27
			Treatment mean	2.79	3.22	2.51	3.09	2.90
6	Winter	148	G	1.54	1.20	1.19	1.53	1.37
			M	2.42	3.48	2.20	3.19	2.82
			GK	2.44	2.09	2.28	2.38	2.30
			MK	3.15	4.04	3.05	4.07	3.58
			PK	2.96	2.36	2.50	2.77	2.65
			Treatment mean	2.50	2.63	2.24	2.79	2.54

[1] G—Guinea grass; M—Merker grass; GK—Guinea-kudzu; MK—Merker-kudzu; PK—Para-Carib-kudzu.
[2] Age of kudzu was 160 days in first cutting.

from 2.30 to 5.38 tons per acre; for the dry Merker-kudzu from 3.58 to 6.40 tons per acre; and for the dry Para-Carib-kudzu from 2.27 to 3.95 tons per acre. The highest yields were obtained during the summer.

The growth period for the six cuttings was 602 days, not counting the 90-day period for the kudzu that was planted before the first crop. The dry yields per acre per year of the respective crops were 9.46 tons of Guinea grass, 13.01 tons of Merker grass, 12.83 tons of Guinea-kudzu, 16.76 tons of Merker-kudzu, and 10.99 tons of Para-Carib-kudzu. The green yields per acre per year were about four times the values reported for the dry yields. The Merker-kudzu association gave the highest yield, equivalent to about 67 tons, green weight, per acre per year. The mean moisture contents

TABLE 2.—*Mean dry yields, in tons per acre, under all treatments, of each of the 6 grass and grass-kudzu cuttings, and test of significance*

Cutting No.	Guinea	Merker	Guinea-kudzu	Merker-kudzu	Para Carib-kudzu	L. S. D. at—	
						1-percent point	5-percent point
1	2.73	3.43	3.47	3.97	3.24	0.45	0.34
2	1.87	2.95	3.12	4.65	3.01	.58	.44
3	2.96	3.38	4.15	5.04	3.00	.61	.46
4	4.47	5.66	5.36	6.41	3.99	.71	.53
5	2.20	3.21	2.85	3.95	2.27	.60	.45
6	1.45	3.06	2.25	3.81	2.58	.61	.46

TABLE 3.—*Mean dry yields, in tons per acre, for each treatment of all the respective grass and grass-kudzu cuttings, and test of significance*

Cutting No.	Check	Ca	P	CaP	L. S. D. at—	
					1-percent point	5-percent point
1	3.27	3.52	2.99	3.65	0.32	0.23
2	2.64	3.35	2.73	3.76	.98	.71
3	3.48	3.78	3.50	4.06	1.15	.84
4	4.61	5.52	4.94	5.64	.82	.60
5	2.76	3.19	2.58	3.06	.65	.47
6	2.59	2.76	2.26	2.89	.65	.45

of the green grasses varied from 67.2 to 71.3 percent and of the kudzu from 73.6 to 74.9 percent.

The mean dry yields, in tons per acre, for all treatments of each of the 6 grass and grass-kudzu cuttings and tests of significance are reported in table 2, and per treatment of all the respective grass and grass-kudzu cuttings in table 3.

There were highly significant differences between the mean dry yields of the grasses. The Merker grass-kudzu association gave the highest yields in all the cuttings. There was a highly significant response to treatments for

the fourth cutting, a significant response for the second cutting, and no response for the first, third, fifth, and sixth cuttings. Although in general there were no significant differences between yields attributable to treatments for the first, fifth, and sixth cuttings, the application of calcium significantly increased the crop yields. The significant responses obtained in the second and fourth cuttings are attributed to the effect of calcium, not phosphorus. Throughout the whole experiment the increase attributable to the application of lime to the Merker-kudzu was from 24.74 to 30.00 tons of dry forage per acre, or 2.77 tons of dry forage (table 1) per acre per year, equivalent to 9.23 tons of green forage containing 70 per cent of water. Assuming that a 1,000-pound cow ate 70 pounds of that green forage per day, the increase of 9.23 tons of green forage from lime application was equivalent to a carrying capacity of 264 cow-days per acre.

TABLE 4. *Analysis of variance for the combined 5 cuttings of the grass and grass-kudzu associations calculated from dry yields in terms of hundredweights per acre*

Source of variation	D. F.	S. S.	Variance	*F*
Total	119	47,145.8		
Blocks	5	2,512.7		
Treatments	3	4,638.9	1,546.3	4.83
Error (a) blocks and fertilizer	15	4,797.4	319.8	
Grasses[1]	4	22,033.0	5,508.2	44.28
Treatments and grasses	12	3,215.3	267.9	2.15
Error (b)	80	9,948.5	124.4	
P_2O_5	1	92.3	92.3	
Ca	1	4,473.7	4,473.7	13.99
Ca + P_2O_5	1	72.0	72.0	

[1] Includes kudzu-grasses.

The statistical analysis for the combined five cuttings is reported in table 4; the sixth cutting was discarded because of too many missing plots. There was a highly significant response due to grasses and a significant response due to treatments and to the interaction between treatments and grasses (table 4). Among the treatments, there was a highly significant response only for calcium. The grasses responded differently in yield to the calcium; the Merker and Merker-kudzu responded highly significantly but the Guinea, Guinea-kudzu, and Para-Carib-kudzu did not respond (table 5). None responded to phosphorus.

The yields of kudzu and of the grasses grown in association with it are given separately. The dry-yield data, in tons per acre per treatment, for each of the six cuttings, are reported separately for the kudzu and grasses in table 6. The mean dry yield of kudzu per cutting varied from 1.02 to

TABLE 5.—*Mean dry yields, in tons per acre, of the 5 combined cuttings of the grass and the grass-kudzu associations, as related to treatments*

Treatment	Mean dry yield of[1]—				
	Guinea	Merker	Guinea-kuzdzu	Merker-kudzu	Para-Carib-kudzu
Check	2.85	3.06	3.60	4.30	2.88
Calcium	3.08	4.19	3.88	5.19	3.01
Phosphorus	2.51	3.25	3.83	4.09	3.06
Calcium-phosphorus	2.95	4.34	3.81	5.63	3.46

[1] Least significant differences between the means of two grasses with the same or different treatments are 0.64 for the 1-percent point and 0.85 for the 5-percent point.

TABLE 6.—*Separate and total dry yields, in tons per acre, of 6 cuttings of Guinea, Merker, and Para-Carib grasses grown in association with kudzu, as related to treatments*

Cutting No.	Treatment	Yield of grasses indicated[1]								
		G	K	GK	M	K	MK	P	K	PK
1	Check	0.80	2.67	3.47	1.36	2.32	3.68	1.37	1.71	3.08
	Ca	1.29	2.24	3.53	1.74	2.54	4.28	2.10	1.34	3.44
	P	1.40	1.80	3.20	1.25	2.11	3.36	1.70	1.18	2.88
	CaP	1.40	2.09	3.49	2.30	2.23	4.53	2.18	1.36	3.54
2	Check	1.71	1.07	2.78	2.35	1.40	3.75	1.59	.86	2.45
	Ca	2.21	.94	3.15	4.45	.85	5.30	2.50	.53	3.03
	P	2.25	.87	3.12	2.61	.68	3.29	2.48	.55	3.03
	CaP	2.57	.85	3.42	5.40	.86	6.26	2.96	.58	3.54
3	Check	2.42	1.65	4.07	3.00	1.83	4.83	1.92	.99	2.91
	Ca	2.56	1.65	4.21	3.47	1.62	5.09	1.65	.82	2.47
	P	3.04	1.26	4.30	3.00	1.46	4.46	2.10	1.08	3.18
	CaP	2.74	1.28	4.02	3.77	1.09	4.86	2.31	1.12	3.43
4	Check	3.86	1.21	5.07	3.45	2.09	5.54	2.56	1.20	3.76
	Ca	3.45	2.02	5.47	5.00	1.91	6.91	2.40	1.42	3.82
	P	4.45	1.19	5.64	4.23	1.58	5.81	2.53	1.51	4.04
	CaP	3.84	1.50	5.34	5.55	1.80	7.35	3.11	1.06	4.17
5	Check	1.70	.92	2.62	2.33	1.46	3.79	1.28	.93	2.21
	Ca	2.02	1.03	3.05	3.13	1.25	4.38	1.60	.71	2.31
	P	1.67	.95	2.62	2.24	1.27	3.51	1.44	.66	2.10
	CaP	2.00	.85	2.85	2.84	1.46	4.30	1.81	.65	2.46
6	Check	1.46	.98	2.44	1.96	1.19	3.15	1.83	1.13	2.96
	Ca	1.21	.88	2.09	3.09	.95	4.04	1.25	1.11	2.36
	P	1.44	.84	2.28	1.87	1.18	3.05	1.47	1.03	2.50
	CaP	1.18	1.20	2.38	2.59	1.48	4.07	1.83	.94	2.77
Mean		2.19	1.33	3.53	3.04	1.53	4.57	2.00	1.02	3.02

[1] G—Guinea grass; M—Merker grass; GK—Guinea-kudzu; MK—Merker-kudzu; PK—Para-Carib-kudzu.

1.53 tons per acre and that of the associated grasses from 2.00 to 3.04 tons. The mean dry yield of kudzu per acre per year, based on 692 days of growth for the six cuttings, varied from 3.22 to 4.82 tons equivalent to from about 13 to 19 tons of green kudzu. The mean dry yield of the grasses grown in the association based on a growth period of 602 days, varied from 7.27 to 11.06 tons per acre per year. The ratio is about 2.3 to 1.0 of grass to kudzu.

PROTEIN CONTENT

The protein content in the first cutting of the 70-day-old grasses grown in association with the 160-day-old kudzu, was improved as indicated by the data in table 7. The mean protein content on a dry basis of the kudzu varied from 16.26 to 17.27 percent. That of the Guinea grass increased from 7.10 to 8.16 percent and that of Merker grass from 7.97 to 8.85 percent, when

TABLE 7.—*Protein contents (percentage on dry basis) of crops in the first cutting[1] of the grass and the grass-kudzu associations, as related to treatments*

Crop	Check	Ca	P	CaP	Mean
Guinea grass	7.12	7.50	6.88	6.88	7.10
Merker grass	9.00	7.63	7.75	7.50	7.97
Guinea grass[2]	8.25	8.75	7.88	7.75	8.16
Kudzu	16.31	16.81	17.06	15.94	16.53
Merker grass[2]	8.25	8.69	8.00	10.44	8.85
Kudzu	16.06	16.25	15.60	17.13	16.26
Para-Carib grass[2]	9.50	9.25	9.25	9.63	9.41
Kudzu	17.56	17.88	17.44	16.19	17.27

[1] Age of grass, 70 days, and of kudzu, 160 days.
[2] Grown in association with kudzu.

grown in association with the legume. The mean protein content on a dry basis of the Para-Carib grass grown in association with the legume was 9.41 percent, while that reported earlier by Bonnet and Riera (1) for this grass alone was between 3 and 4 percent.

The increase per acre per year of the protein content of the dry grasses grown in Fajardo clay in association with the tropical kudzu was about 300 pounds for the Guinea and Merker grasses, respectively, and 1,200 pounds for the Para-Carib grass. The net profit[4] per acre per year attributable to the increased protein content is estimated to be $71 for the Guinea and Merker grasses, respectively and $288 for the Para-Carib grass.

[4] Calculated on the basis of $25 per 100 pounds of protein in feed and of a cost of production delivered at the stable of $4 as informed by the Department of Animal Husbandry.

Warmke et al. (4) found no difference between the mean protein content of 10 cuttings of Merker grass grown from 1948 to 1950, in the fertile alluvial Toa silty clay. The actual average elapsed time between harvests was 99 days. The protein content of the grass was found to be 3.7 and 4.1 per cent, respectively, when grown alone and when grown in association with kudzu.

The statistical analysis for the kudzu alone and when grown in association with Guinea, Merker, and Para-Carib grasses, respectively, in the combined first five cuttings is reported in table 8. There were highly significant differences between the mean yields obtained when kudzu was grown in association with different grasses but none when it was grown under the different treatments. The mean dry yields of kudzu were 1.35, 1.62, and 1.07 tons per acre, respectively, when grown in association with Guinea, Merker, and Para-Carib grasses. The yield of kudzu grown in association with Merker

TABLE 8.—*Analysis of variance for kudzu grown in association with Guinea, Merker, and Para-Carib grasses, in the combined first 5 cuttings, calculated from dry yields of kudzu in terms of hundredweights per acre*

Source of variation	D.F.	S.S.	Variance	F[1]
Total	71	5,341.8		
Blocks	5	845.6		
Treatments	3	92.8	30.9	Not significant
Error (a) blocks and treatments	15	984.9	65.7	
Grasses	2	1,429.0	714.5	15.3
Treatments and grasses	6	120.2	20.0	Not significant
Error (b)	40	1,869.3	46.7	

[1] Least significant differences between mean dry yields of kudzu are 0.26 tons per acre at the 1-percent point and 0.19 at the 5-percent point.

grass was highly significantly better than when grown in association with Guinea or Para-Carib grasses. The yield of kudzu grown in association with Guinea grass was highly significantly better than when grown in association with Para-Carib grass.

Bonnet et al (3) reported that the three leguminous crops, velvetbeans, soybeans, and crotalaria, responded significantly at the 1-percent point to the application of lime and phosphorus, while cowpeas showed no response, in a field adjacent to the same acid Fajardo clay where the tropical kudzu showed no response.

MINERAL CONTENT

The data for calcium, magnesium, manganese, phosphorus, and iron, for the first cutting of grasses and of the kudzu-grass associations are reported in table 9. The analyses were made in composite samples for each of the

TABLE 9.—*Calcium, magnesium, manganese, phosphorus, and iron (parts per million) contents of the first cutting of the grasses and the kudzu-grass associations (dry basis) grown under different treatments*

Crop	Treatment	Calcium	Magnesium	Manganese	Phosphorus	Iron
Guinea grass	Check	4,865	2,799	263	1,465	339
	Ca	7,662	4,180	213	1,063	293
	P	5,032	2,787	330	1,377	294
	CaP	8,494	3,614	171	1,321	204
Merker grass	Check	3,008	1,931	116	1,463	898
	Ca	4,762	2,237	92	2,144	325
	P	2,967	2,083	158	1,038	647
	CaP	4,120	2,008	107	1,587	209
Guinea grass	Check	4,672	3,845	289	1,800	572
	Ca	11,251	3,416	209	1,446	233
	P	5,430	3,025	334	1,507	460
	CaP	12,377	3,870	171	1,719	504
Kudzu	Check	7,251	4,930	381	1,935	852
	Ca	11,550	4,168	188	1,737	686
	P	9,449	4,378	343	1,884	1,029
	CaP	12,279	3,913	155	1,838	762
Merker grass	Check	6,915	2,217	142	1,937	287
	Ca	5,160	2,221	102	2,836	284
	P	3,333	2,332	168	2,095	478
	CaP	4,436	2,314	102	2,654	480
Kudzu	Check	7,751	4,552	298	2,013	466
	Ca	7,658	4,307	151	1,568	771
	P	7,554	5,397	362	1,915	1,415
	CaP	10,929	4,140	217	2,154	1,263
Para-Carib grass	Check	3,323	1,981	196	2,128	700
	Ca	5,476	2,126	85	1,906	213
	P	3,731	2,313	147	1,870	571
	CaP	5,010	2,173	75	1,803	353
Kudzu	Check	5,768	3,852	328	2,316	1,463
	Ca	11,480	3,519	161	1,955	999
	P	7,587	5,002	337	2,365	1,959
	CaP	11,554	4,279	147	1,926	1,827

four treatments. The statistical interpretations of the data are given in tables 10 and 11.

There was a highly significant difference in the contents of calcium, magnesium, manganese, phosphorus, and iron for each of the grasses, grass-kudzu associations, and kudzu.

Guinea grass absorbed more calcium, magnesium and manganese than Merker grass. Guinea grass grown in association with kudzu absorbed

TABLE 10.—*Mean calcium, magnesium, manganese, phosphorus, and iron contents (parts per million) of the first cuttings of the grasses and grass-kudzu associations and least significant differences, as affected by treatments*

Grasses[1] and associations	Ca × 100	Mg × 100	Mn × 10	P × 100	Fe × 10
G	65	34	24	13	28
M	37	20	12	16	52
G_K	84	35	25	16	44
K_G	101	43	27	18	83
M_K	50	22	13	24	38
K_M	85	46	26	19	98
P_K	44	22	13	19	46
K_P	91	41	24	22	156
L.S.D. at 5-percent level	23	6	6	4	33
L.S.D. at 1-percent level	31	8	8	6	45

[1] G—Guinea grass; M—Merker grass; G_K—Guinea with Kudzu; M_K—Merker with kudzu; P_K—Para-Carib with kudzu; K_G—kudzu with Guinea; K_M—kudzu with Merker; K_P—kudzu with Para-Carib.

TABLE 11.—*Mean calcium, magnesium, manganese, phosphorus, and iron, contents (parts per million) of the first cuttings of the grasses and grass-kudzu associations and least significant differences, as affected by treatments*

Treatment	Ca × 100	Mg × 100	Mn × 10	P × 100	Fe × 10
Check	54	32	25	19	70
Ca	81	33	15	18	47
P	56	34	27	18	86
CaP	86	33	14	18	70
L.S.D. at the 5-percent level	17	6	4	4	23
L.S.D. at the 1-percent level	23	8	5	6	31

more calcium, magnesium and manganese than Merker and Para-Carib grasses grown in association with kudzu, (table 10).

There was no difference in the amount of phosphorus absorbed by Guinea and Merker grasses when grown alone but Merker grass absorbed more phosphorus than Guinea and Para-Carib grasses when the three grasses grew in association with kudzu.

There was no difference in the amount of iron absorbed by the grasses.

Kudzu absorbed more calcium, magnesium, and iron than the three grasses and more manganese than Merker and Para-Carib grasses; but as much as Guinea grass.

There were highly significant differences attributable to treatments in the calcium and manganese contents of the grasses and grass-kudzu associations, significant differences in the iron content, and no significant difference in the magnesium and phosphorus contents. Bonnet and Riera (1, 2) found previously with Para-Carib grass that: "When lime or lime and phosphorus were applied, there was a highly significant increase of calcium and phosphorus and a highly significant decrease of manganese in the grass but the iron and magnesium contents were not affected. When phosphorus was applied without lime, there was a significant increase of phosphorus in the grass, but no significant change in the other minerals. There was also a significant difference between the phosphorus content of the grass that received phosphorus and that with calcium and phosphorus. The latter had the higher content."

The addition of lime or lime and phosphorus increased the calcium content and decreased the manganese content of the grasses and grass-kudzu associations (table 11). The addition of lime decreased the iron content. There was no difference in the magnesium and phosphorus contents. The addition of phosphorus with the lime increased the iron content but there was no change when the phosphorus was added alone. There was no significant interaction between lime and phosphorus to cause changes in the iron content.

Summary

The effect of lime and phosphorus added to an acid soil of Puerto Rico was studied in relation to the yields and mineral contents of Guinea and Merker grasses, and of these grasses and Para-Carib grown in association with a legume, tropical kudzu, and as well as of kudzu itself. The results were as follows:

1. There was a highly significant response of the grasses to the lime application but the kudzu did not respond. The Merker grass-kudzu association produced the highest yields.

2. There was no significant response of either the grasses or kudzu to the addition of phosphorus.

3. The increase of green Merker grass-kudzu forage from lime application was equivalent to a carrying capacity of 264 cow-days per acre.

4. The protein content of the grasses grown in association with the kudzu was increased.

5. There was a highly significant difference in the contents of calcium,

magnesium, manganese, phosphorus, and iron for each of the grasses, grass-kudzu associations, and kudzu.

6. Guinea grass absorbed more calcium, magnesium, and manganese than Merker grass. Guinea grass grown in association with kudzu absorbed more calcium, magnesium, and manganese than Merker and Para-Carib grasses grown in association with kudzu.

7. There was no difference in the amount of phosphorus absorbed by Guinea and Merker grasses when grown alone, but Merker grass absorbed more phosphorus than Guinea and Para-Carib grasses when the three grasses grew in association with kudzu.

8. There was no difference between the amounts of iron absorbed by the grasses.

9. Kudzu absorbed more calcium, magnesium, and iron than the three grasses and more manganese than Merker and Para-Carib grasses, but only as much as Guinea grass.

10. There were highly significant differences resulting from treatments in the calcium and manganese contents of the grasses and grass-kudzu associations, significant differences in the iron content, and no significant difference in the magnesium and phosphorus contents.

11. The addition of lime or lime and phosphorus increased the calcium content and decreased the manganese content of the grasses and grass-kudzu associations. The addition of lime decreased the iron content. There was no difference in the magnesium and phosphorus contents. The use of phosphorus with the lime increased the iron content, but there was no change when the phosphorus was added alone.

Resumen

Se estudiaron los efectos de la adición de cal y fósforo a un suelo ácido de Puerto Rico, en lo que concierne a los rendimientos y contenido de minerales de las yerbas Guinea y Merker, de la combinación de éstas y la Pará-Caribe, desarrolladas en asociación con la leguminosa Kudzú tropical, como también el Kudzú solo. Los resultados fueron los siguientes:

1. Las yerbas respondieron en forma altamente significativa a las aplicaciones de cal. No fué así en lo que respecta al Kudzú. La yerba Merker, al crecer asociada con el Kudzú, produjo los rendimientos mayores.

2. Ni las yerbas, ni el Kudzú, respondieron significativamente a las aplicaciones de fósforo.

3. El aumento registrado en la cantidad del forraje, en la asociación de la yerba Merker y el Kudzú, cuando se aplicó la cal, equivalió a una capacidad de sostenimiento de 264 vacasdías por acre.

4. Se aumentó el contenido de proteína en las yerbas que crecieron en asociación con el Kudzú.

5. Hubo diferencias altamente significativas entre los contenidos de calcio, magnesio, fósforo y hierro en cada una de las yerbas, en las asociaciones de yerba y Kudzú y en el Kudzú solo.

6. La yerba Guinea absorbió más calcio, magnesio y manganeso que la yerba Merker. La Guinea, en asociación con el Kudzú absorbió más calcio, magnesio y manganeso que la Merker y la Pará-Caribe, cuando crecieron asociadas con el Kudzú.

7. No hubo diferencia alguna en la cantidad de fósforo que absorbieron las yerbas Guinea y Merker cuando crecieron solas, pero la Merker absorbió más fósforo que la Guinea y la Pará-Caribe, cuando las tres yerbas crecieron en asociación con el Kudzú.

8. No hubo diferencia alguna en la cantidad de hierro que absorbieron las yerbas.

9. El Kudzú absorbió más calcio, magnesio y hierro que las tres yerbas y más manganeso que las Merker y Pará-Caribe, pero sólo la misma cantidad que la Guinea.

10. Hubo una diferencia altamente significativa, como resultado de los tratamientos, en el contenido de calcio y manganeso de las yerbas solas y en la asociación de Kudzú y las yerbas; fué significativa en el contenido de hierro y nula en cuanto a magnesio y fósforo.

11. La adición de cal, o de cal y fósforo, aumentó el contenido de cal y disminuyó el de manganeso en las yerbas solas y en las asociaciones del Kudzú y las yerbas. Cuando se añadió cal, disminuyó el contenido de hierro, pero no hubo diferencia en el contenido de magnesio y fósforo. Cuando se mezclaron y añadieron el fósforo y la cal, aumentó el contenido de hierro, pero no hubo cambio alguno cuando se añadió el fósforo solo.

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EVALUATION OF THE LIME REQUIREMENT OF TROPICAL SOILS IN TERMS OF OTHER SOIL CHARACTERISTICS

M. A. Lugo López, F. Abruña, and J. Roldán[1]

Introduction

Liming acid soils is a very old soil-management technique that is widely practiced in many progressive agricultural areas, but is still not in very widespread use throughout the Tropics. The dual role of lime in plant nutrition, supplying available calcium and affecting the physiological status of the soil as a medium for plant growth, is well known. Considerable literature have been published concerning many practical aspects of liming. However, there is still a lack of fundamental information regarding the interrelation between the lime requirement and other soil properties. The need for such information is particularly acute when dealing with tropical soils and crops.

This paper reports an attempt to correlate the lime requirement of some tropical soils from Puerto Rico with certain soil characteristics such as pH, cation-exchange capacity, clay content, organic matter, and predominating clay-mineral type. It should be emphasized that for the purpose of this work the lime requirement of a soil is defined as the quantity of limestone required to raise the pH of an acid soil to 6.5.

Materials and Methods

The samples used in this study were selected from a large group collected by Jeffries and Bonnet in connection with their study of soil minerals in Puerto Rico soils (2).[2] The clay minerals were identified by Jeffries by matching X-ray diffraction patterns of the clay fraction with standards of known minerals (1). The clay content was determined by the beaker decantation method. Organic-matter determinations were made using the chromic acid titration method (3). The pH was obtained by using a Beckman potentiometer. Cation-exchange capacity was determined by the ammonium acetate procedure (5). Lime requirement was determined by adding increments of $CaCO_3$ to several 10-gm. soil samples, adjusting the volume of all samples to 150 ml. with distilled water, and measuring the pH values after 3 hours of shaking in a Ross-Kershaw apparatus (4).

[1] Associate Soil Scientist, formerly Assistant Soil Conservationist, now Soil Scientist BPI-SCS Cooperative Research Project, and Research Assistant in Chemistry, respectively, Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P. R.

[2] Numbers in parentheses refer to Literature Cited p. 160.

Presentation of Data and Discussion

The lime requirement of some tropical soils from Puerto Rico included in the investigation varies from 0.2 to 5.8 tons of limestone to the acre, as shown in table 1. A sample of weathered parent material required the equivalent of 9.7 tons to the acre of $CaCO_3$ before reaching pH 6.5. In 11 soils the predominant clay mineral was found to be kaolin, while minerals of a 2:1 lattice structure, presumably beidellite, were predominant in the

Table 1.—*The relation of lime requirement to pH, cation-exchange capacity, and various other factors for certain tropical soils*

Soil type	Sample No.	Depth	Predominant clay mineral	Clay content	Cation exchange capacity (dry soil)	Organic matter	pH	Lime requirements per acre
		Inches		*Percent*	*M.e./100 gm.*	*Percent*		*Tons*
Bayamón sandy clay	165	18	Kaolin	25.25	5.22	1.80	5.00	1.4
Teja loam	70	12		10.40	7.94	.37	5.15	.6
Sabana Seca sandy clay	194	12		21.50	7.11	2.05	5.70	.4
Viví sandy loam	73	0–15		14.40	7.70	.89	4.20	2.0
Río Piedras clay	190	[1]		62.17	15.11	1.03	4.10	5.0
Las Piedras clay loam	66	0–20		15.50	7.06	2.30	5.40	.6
Matanzas clay	119	[1]		60.50	7.12	.85	5.90	.4
Cialitos clay	83B	45+		19.05	13.34	.52	4.45	5.8
Catalina stony clay	172	[1]		26.17	11.16	.44	4.75	3.7
Los Guineos clay	186	0–24		3.70	8.70	7.45	5.15	1.1
Los Guineos clay	185	24–32		23.15	9.18	3.83	4.85	3.0
Cabo Rojo clay	134	24–36		34.25	11.29	1.49	6.10	.2
Los Guineos clay	182	[2]		16.95	25.91	.20	4.60	9.7
Las Piedras clay loam	64	44–48	Beidellite	28.55	24.75	.18	5.50	.2
Múcara silty clay loam	1	0–6		29.87	30.97	4.84	5.55	.2
Múcara silty clay loam	2	0–3		33.77	30.85	4.78	5.30	.4
Múcara silty clay loam	3	3–7		35.66	30.48	3.86	5.10	.5

[1] Surface.

[2] Decomposed parent material.

remaining 6 samples. The soils selected had an original pH value ranging from 4.10 to 6.10, the mean value for all 17 being around pH 5.10. The percentage of clay particles ranged from 3.7 in the upper 2 feet of Los Guineos soil to 62.2 in the surface layer of a Río Piedras lateritic clay. The differences in cation-exchange capacity were very marked, the kaolin dominated soils averaging about 9 m.e. per 100 gm. of dry soil while mean values of about 26 m.e. were found in beidellite-dominated soils. There was considerable variability in exchange capacity within the kaolinitic soils,

but the values for beidellitic soils were fairly constant. The organic-matter content ranged from 0.2 to 7.4 percent with a mean value of 2.2 percent.

Statistical analyses were performed on all the data (table 2). The regression of the lime requirement on each individual factor was worked out

TABLE 2.—*Analysis of variance for regression analysis of various factors studied*

Source of variation	Degrees of freedom	Sum of squares	Variance	f
Lime requirement on pH				
Total	16	111.28		
Regression	1	52.851	52.851	13.569**
Error	15	58.424	3.895	
Lime requirement on pH and organic matter				
Total	16	111.28		
Regression	2	59.01	29.505	7.902**[1]
Error	14	52.27	3.734	
Lime requirement on pH of kaolinitic soils				
Total	10	37.176		
Regression	1	23.066	23.066	14.713**
Error	9	14.110	1.568	
Lime requirement on cation-exchange capacity of kaolinitic soils				
Total	10	37.176		
Regression	1	29.638	29.6380	35.387**
Error	9	7.538	.8376	
Lime requirement on cation-exchange capacity and pH of kaolinitic soils				
Total	10	37.176		
Regression	2	32.201	16.100	25.89[2]**
Error	8	4.975	.6219	

[1] t pH = −3.417**
t o.m. = −1.476
[2] t pH = −2.03
t c.e.c. = 3.83**

taking all soils together without considering whether the predominant clay mineral was kaolin or beidellite. The regression of lime requirement on pH was found to be: $Y = 18.39 - 3.196\ X$, where Y is the lime requirement and X is the pH value. The regression coefficient is highly significant. A correlation coefficient of −0.70 was obtained. Thus, accurate predic-

tions of the lime requirement of soils can be made on basis of pH values exclusively, disregarding any other factors. The organic matter and cation-exchange capacity explained part of the variability observed in lime requirements, but no significant regressions were obtained in either case.

A multiple regression was worked out for lime requirement on pH and organic matter, which were the two factors explaining most of the variability observed in lime-requirement values. There was an increase in the variability explained by this regression but it was not significantly higher than that explained by pH alone. A correlation coefficient of 0.73 was obtained.

Further statistical analyses were made after arranging the data into two groups according to the predominant clay mineral. For soils dominated by kaolinitic clays the regression of lime requirement on pH was: $Y = 15.26 - 2.632\ X$, where Y is the lime requirement and X is the pH. The regression coefficient is highly significant. A correlation coefficient of -0.80 was obtained which points out to the close degree of association between these two soil characteristics. The regression of lime requirement on cation-exchange capacity of kaolinitic soils was very satisfactory giving the equation: $Y = 3.048 + 0.5774\ X$, where Y is the lime requirement and X is the exchange capacity. The regression coefficient was highly significant. A positive correlation coefficient of 0.90 was obtained. About 80 percent of the variability observed in lime requirement values can be explained on basis of the cation-exchange capacity of kaolin-dominated soils.

A regression of the lime requirement on pH and cation-exchange capacity was worked out. About 87 percent of the variability in lime requirement could be explained in terms of both of these factors taken together. However, the difference in the variability explained by this regression and the one for lime requirement on cation-exchange capacity is not significant.

Further attempts to explain the variability in lime requirement of beidellite-dominated soils in terms of other soil characteristics were not successful. A correlation coefficient of -0.75 was obtained between lime requirement and soil pH, but the regression coefficient was not significant.

When dealing with soils the predominating clay mineral of which is not known, it may be advisable to use the original pH values as a basis to predict their lime requirement. If the predominating clay mineral is known to be kaolin a better approximation is possible by making use of the regression of lime requirement on cation-exchange capacity, although the regression based on pH will also give fairly accurate approximations.

More research is contemplated along this line. There is a possibility that more accurrate predictions could be made if a larger number of samples were included in the statistical analyses. This type of equation in addition to giving fundamental information about lime requirements and soil properties affecting it, also provides for farmers, extension agents, and

teachers of agriculture a rather simple way of estimating the lime needs of soils. This is particularly true of the relation between lime requirement and pH. The latter can easily be determined colorimetrically in the field by any skilled operator.

Summary

The quantity of limestone required to bring the pH of various acid Puerto Rican soils to 6.5 was investigated and found to vary from several hundred to several thousands pounds per acre. To investigate the relation of clay-mineral type, clay content, cation-exchange capacity, organic-matter content, and pH to lime requirement, these properties were determined for several soils. A highly significant regression of lime requirement on pH was obtained which can be expressed by the equation: $Y = 18.39 - 3.196\ X$, where Y is the lime requirement and X is the pH value. Multiple regressions including other factors did not significantly increase the variability which could be explained on terms of the first regression.

Further analysis were made by arranging the data according to the predominant clay mineral. For kaolinitic soils highly significant correlations were obtained between lime requirement and either pH or cation exchange capacity. The regressions were: (a) $Y = 15.26 - 2.632$ pH, and (b) $Y = 3.048 + 0.5774$ (cation-exchange capacity), where Y is the lime requirement.

A regression of lime requirement on both factors did not significantly increase the variability explained by the second equation. No significant regressions were obtained for beidellitic soils.

Resumen

La cantidad de cal necesaria para subir el pH de varios suelos ácidos de Puerto Rico hasta 6.5 fluctúa entre varios cientos y varios miles de libras. Para investigar la relación entre el mineral predominante en la fracción arcillosa del suelo, el contenido de arcilla, la capacidad de intercambio, el contenido de materia orgánica, el valor pH y la cantidad de cal requerida, fuéque se determinaron estos factores en el laboratorio. Se obtuvo una regresión altamente significativa entre cal requerida y pH que se puede expresar por la ecuación: $Y = 18.39 - 3.196\ X$, donde Y es la cal requerida y X es el valor pH. No hubo un aumento significativo en la variabilidad explicada por la regresión al incluir otros factores.

Los datos se agruparon, luego, de acuerdo con el mineral predominante en la fracción arcillosa. Para suelos donde predomina el caolín se encontraron correlaciones altamente significativas entre cal requerida y pH, y entre cal requerida y capacidad de intercambio. Las regresiones se pueden expresar así: (a) $Y = 15.26 - 2.632$ pH, (b) $Y = 3.048 + 0.5774$ (capacidad

de intercambio) donde Y representa la cantidad de cal requerida para subir el pH del suelo a 6.5.

Un intento para establecer una correlación entre la cantidad de cal requerida y ambos factores no aumentó significativamente la variabilidad explicada por la regresión sobre la explicada por la segunda ecuación (b). No se obtuvieron regresiones significativas en el caso de los suelos cuya fracción arcillosa estaba dominada por la beidelita.

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THE RATE OF INFILTRATION OF LATERITIC SOILS[1]

J. A. Bonnet and M. A. Lugo López[2]

Introduction

Lateritic soils are products of humid tropical weathering of rocks which are usually basic in reaction, resulting in acidic material high in free sesquioxides, low in free silica and exchange capacity, very permeable to water and air, and, in many instances, of great depth, but exhibiting little or no differentiation into soil horizons. They are generally found in regions with mean annual temperatures above 70°F and rainfall above 80 inches.

The red and yellow lateritic soils of the Tropics have a relatively rapid rate of percolation through their profiles and are easily worked after a rain. They are resistant to erosion as compared to other soils of similar climatic, relief and management conditions. This field behavior is peculiar because lateritic soils contain a high clay content or of particles whose diameter is less than 2 microns.

This paper presents data on the infiltration rate of lateritic soils o Puerto Rico and discusses the related physical factors.

Soils Studied

Representative types were selected, of each of the lateritic great soil groups recognized in Puerto Rico (10),[3] namely, Laterite, Reddish Brown Lateritic, and Yellowish Brown Lateritic. A typical Laterite occurs at the Las Mesas Plateau in western Puerto Rico. The topography is hilly and the underlying rock is serpentine, a product of the metamorphosis of pteridotite. The soil was classified by Roberts (10), as Nipe clay, following the one described in Cuba by Bennet and Allison (2). It is red and very deep, extending in many places down to 30 or 40 feet. The soil is more or less uniform in physical properties from the surface layer to bedrock. A characteristic feature is the presence in the profile of iron concretions of various sizes. The total exchange capacity ranges from 2 to 3 m.e. per 100 gm. of dry soil and gives the soil a poor capacity to retain available cation nutrients. Much care must be exercised in fertilization in order to avoid heavy nutrient losses. Nipe clay is a very poor agricultural soil, low in nitrogen and very low in available phosphorus, calcium, and potassium (3).

The Reddish Brown Lateritics are the most extensive group of lateritic soils in Puerto Rico. The largest area is planted to coffee but considerable

[1] Contribution from the Department of Soils, Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P. R.

[2] Head of the Department of Soils and Associate Soil Scientist, respectively.

[3] Numbers in parentheses refer to Literature cited p. 166.

areas are planted to pineapple, sugarcane, and other crops. Their exchange capacity ranges from 8 to 16 m.e. per 100 gm. of soil or about four to five times as large as that of the Laterite, but considerably lower than the more fertile soils of the Tropics (5). Catalina clay is typical of this group; it is very deep, strongly acid, red, friable, (4), and can be easily worked. The Catalina series is associated with the Cialitos, Alonso, Malaya, and other soil series of the humid hilly and mountain area of Puerto Rico. They are derived from tuffaceous volcanic rocks; their inherent fertility is moderate and they are low in available phosphorus and calcium. Alonso clay is very similar in physical and chemical characteristics to Catalina clay, but it is a more productive soil, largely planted to coffee. It can be readily identified by the brownish purple color throughout the profile. Alonso clay has been observed to be less plastic than its red lateritic associates. Matanzas clay is representative of a large extensive group of coastal plain reddish brown lateritic soils which include the Bayamón, Maleza, and other series. They are very valuable agricultural lands; well adapted to sugarcane or fruit growing and have been rated as moderately high in productivity. These soils occur along the north coast and are underlain by tertiary limestone formations. Río Piedras clay is a medium deep acid soil of the uplands, derived from ashy shales. It tends to be more plastic than the other lateritic soils. Its fertility is rather low. This soil is mostly planted to sugarcane and subsistence crops, but considerable portions of the shallower areas are in native pastures of very low carrying capacity.

Coto clay is a typical Yellowish Brown Lateritic soil representative of a rather inextensive group of soils occurring in northwest and northern Puerto Rico. The color is yellowish brown in the surface layer but gradually changes to light yellow with depth. It is acid throughout the profile until the underlying tertiary limestone rock is encountered. The depth to rock is very variable although on a typical profile it has been found at 5 feet. Coto clay is a very valuable soil for farming usually planted to a wide variety of such crops as sugarcane, truck crops, subsistence crops, and tobacco.

Recent mineralogical studies by Jeffries et al (8) indicate that kaolin is the clay mineral of lateritic soils, a fact that explains in part their low exchange capacity; the coarser fractions are almost free of feldspars, which give them their low inherent fertility.

Methods

The buffer-compartment method as outlined by Nelson and Muckenhirn was used (9). The procedure is as follows:

"Three concentric iron rings, each 5 inches in height and 9, 18, and 27 inches respectively in diameter, are driven into the ground 2 or 3 inch surface. The soil inside the two outside rings is kept saturated with water

while the test is running. The infiltration test is run in the soil within the inner 9-inch ring, over which hangs a calibrated 2000 ml. burette, the water reservoir. A volume of 1,043 ml. in this burette is equivalent approximately to one inch of water added to the 9-inch soil core. A pinchcock serves as a valve at the rubber hose that connects the tip of this burette to a small glass tube. The burette is filled with water to the 2000 ml. mark and is stoppered. The stopcock is opened and the starting time is recorded. Water infiltrates rapidly at first, into the soil, until the thin film of water that collects on the top soil touches the end of the small tube. This film serves as a regulator for the water to run from the burette as fast as the soil requires it. The time is recorded every time the burette is emptied to the zero mark. At this time the pinchcock is closed rapidly and the burette is refilled with water. The outfit is kept covered with a canvas."

TABLE 1.—*Mean infiltration rate per hour for six lateritic soils of Puerto Rico*

Soil type[1]	Tests	Mean rate of infiltration in inches per hour given—							
		1	2	3	4	5	6	7	8
	Number	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Nipe clay[2]	4	14.46	8.15	5.58	6.80	12.51	9.47	5.93	6.16
Río Piedras clay	8	31.44	13.88	10.47	10.15	10.85	8.12	7.57	7.83
Catalina clay	20	9.79	6.78	5.96	5.44	5.15	4.02	4.37	4.16
Matanzas clay	4	23.76	15.01	11.76	10.05	7.67	7.09	6.67	5.88
Alonso clay	4	27.26	19.53	15.25	14.65	13.07	11.36	10.51	9.47
Coto clay	12	7.75	5.48	4.65	4.50	4.22	3.92	3.75	3.72

[1] Nipe clay is a Laterite, Coto clay is a Yellowish Brown Lateritic, and the others are Reddish Brown Lateritics.

[2] Test run in two 4-hour periods for 2 successive days.

The test was run for 8 consecutive hours, except in the case of Nipe clay when two 4-hour runs were made on two successive days. The amount of water used every hour was also recorded. Four replicated tests were run side-by-side for the same soil. Mechanical analyses were made by the Bouyoucos-hydrometer technique. Aggregate analysis were made by elutriation using the Kopecky type of apparatus (1).

PRESENTATION OF DATA

The mean infiltration data for six lateritic soils of Puerto Rico, per hour, up to the eighth-hour run is reported in table 1. The data represent the mean values obtained for 4 tests of the Laterite, Nipe clay, 36 tests of the Reddish Brown Lateritic group, and 12 for the Yellowish Brown Lateritic, Coto clay. The Reddish Brown Lateritic group includes 8 tests of Río Piedras clay, 20 of Catalina clay, 4 of Matanzas clay, and 4 tests of Alonso

clay. The Yellowish Brown Lateritic group includes 12 tests of Coto clay.

The percentage of aggregates (0.05 to 2 mm.) and total silt and clay (particles less than 0.05 mm.) aggregated and not aggregated, are reported in table 2. The data for Nipe clay were obtained from the Soil Survey of Puerto Rico (10).

TABLE 2.—*Aggregation analysis and total silt and clay contents of lateritic soils*

Soil type	Depth	Aggregates (0.05 to 2 mm.)	Total silt and clay (less than 0.05 mm.)	Total silt and clay	
				Aggregated	Not aggregated
	Inches	*Percent*	*Percent*	*Percent*	*Percent*
Nipe clay[1]	0–5	67.1	70.9	53.6	46.4
	5–30	70.6	85.9	65.2	34.8
	30–60	37.7	71.3	31.4	68.6
Río Piedras clay	0–12	71.5	83.5	65.8	34.2
	12–22	48.2	91.1	43.2	56.8
	0–10	47.2	96.3	45.2	54.8
Catalina clay	0–6	64.1	95.7	62.5	37.5
	6–9	50.6	98.0	49.5	50.5
	11–22	68.0	98.9	67.6	32.4
	22+	92.2	98.6	92.1	7.9
Alonso clay	0–6	83.6	79.5	79.4	21.6
	6–18	76.4	76.6	69.2	30.8
	18+	70.4	75.2	60.7	39.3
	0–10	63.7	79.3	54.2	45.8
	10–24	73.1	73.9	63.5	36.5
	24	81.5	72.1	74.4	25.6

[1] Data reported by L. D. Baver, p. 475 Soil Survey of Puerto Rico (10).

DISCUSSION

At the beginning of the tests considerable variation is apparent in the rate at which water penetrates the profile. Such variability can be ascribed to the differences in moisture content of the soil at the beginning of the run. Those differences are entirely beyond control since they are almost completely dependent on weather conditions at the time the tests are initiated. The fact that towards the end of the tests those differences are minimized further corroborates this point. At such time, the moisture level in the soils studied is on a more equalized basis and the infiltration rates are then more likely to be the result of soil characteristics than at the beginning. The similarities or differences at the last 3 or 4 hours can be explained on a basis of soil properties.

The mean infiltration rate of the water-saturated Laterite, Nipe clay,

at the eighth-hour run was 6.16 inches (table 1), a very rapid infiltration rate[4] (6).

The mean infiltration rate of the Reddish Brown Lateritic group, at the eighth-hour run varied from 4.16 inches in the 20 tests of Catalina clay to 9.47 inches in 4 tests of Alonso clay. This group has also a very rapid infiltration rate. The mean value for the Río Piedras clay, Catalina clay, Matanzas clay, and Alonso clay, is 6.84 inches.

The mean infiltration rate of the Yellowish Brown Lateritic group, represented by Coto clay at the eighth-hour run, is also very rapid, 3.72 inches.

The aggregate analysis reported in table 2 is an aid for the study of soil structure relationships as pointed out by Baver and Rhoades: "From the physical point of view a soil may be pictured as being made up of mechanical and structural elements. The mechanical elements are the individual primary particles of various sizes, such as sand, silt, and clay. The structural elements are crumbs or granules of various dimensions which have been formed by the aggregation of the smaller mechanical elements. The extent to which a soil breaks up into crumbs or granules may be referred to as the state of aggregation of the soil."

The aggregates of particles above silt size (0.05 mm.) for the lateritic soils reported (table 2) vary from 37.7 to 92.2 percent; and the total silt and clay from 70.9 to 98.9 percent. From 31.4 to 92.1 percent of the total silt and clay is aggregated and 68.6 to 7.9 percent is not aggregated. The data show that the lateritic clays have a high state of aggregation.

It must be considered also that the clay content is a mixture of particles of true clay and of inert free sesquioxides of iron and aluminum that do not expand or contract as true clays. Bonnet (4) reported that a profile of Catalina clay of Puerto Rico contains 70 to 87 percent of total clay consisting of 45 to 61 percent of kaolinitic clay and 20 to 30 percent of free sesquioxides of Fe_2O_3 and Al_2O_3.

The high state of aggregation, content of inert free sesquioxides and the presence of a kaolinitic clay mineral that have limited contraction and expansion when the soil is dry or wet, respectively, are important physical factors that have a bearing in giving lateritic clays a high infiltration rate.

Summary

Fifty-two infiltration tests were conducted on six soil types of Puerto Rico comprising three great soil groups: Laterite, Reddish Brown Lateritic, and Yellowish Brown Lateritic. The mean infiltration rate for the soils was very rapid, fluctuating from 3.72 to 9.47 inches per hour. This high

[4] A soil with more than 2.5 inches of water for the wet run has a very rapid rate of infiltration (6).

infiltration rate is explained on the basis of a very high state of aggregation, the content of inert free sesquioxides, and the presence of kaolinitic type of clay in lateritic soils.

Resumen

Se hicieron 52 pruebas de infiltración en seis tipos de suelos lateríticos representados por los grupos Laterita, Suelos Lateríticos Pardo Rojizos, y Suelos Lateríticos Pardo Amarillentos. La velocidad de infiltración fué muy rápida y varió entre 3.72 y 9.47 pulgadas por hora. Esta velocidad rápida de infiltración se explica a base de una agregación alta de las partículas del suelo, del contenido de sesquióxidos libres de hierro y aluminio y de la presencia de una arcilla del tipo caolín, en los suelos lateríticos.

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MORPHOLOGICAL AND PHYSICOCHEMICAL PROPERTIES OF VARIOUS TROPICAL SOILS FROM EAST-CENTRAL PUERTO RICO

M. A. Lugo-López, M. B. Martínez, and A. R. Riera[1]

Introduction

The mineral soils of east-central Puerto Rico are derived mainly from upper cretaceous rocks such as massive andesitic tuffs, and volcanic and igneous rocks including coarse quartz diorites and granites. Temperature is more or less equal throughout the year as in the rest of the Island and the area as a whole receives as much rainfall as the northern and eastern humid sections. The topography varies from level or nearly level as in the Caguas, Humacao, Yabucoa, and other lowlands through undulating, as in the vicinity of Las Piedras, Juncos, and San Lorenzo, to steep in the surrounding hills and mountains. Large-scale sugarcane farming predominates in the region, but upland rice, corn, root crops, and vegetables are grown on a subsistence basis. Soiling and pasture grasses are also grown extensively throughout the section. In the lowlands adequate drainage is of primary importance to obtain profitable crop yields.

This paper reports the results of a preliminary study of the morphological and some physicochemical properties of selected soil profiles from the region. The objective of the work was to gather some basic knowledge on the characteristics of the most important soils of the area which may lead to a better understanding of their behavior.

Materials and Methods

For the morphological studies pits 4 feet wide, 3 feet long, and 6 feet deep were dug at various selected scattered and distant places in east-central Puerto Rico. Information was then secured on number of horizons, thickness, color, and apparent texture and structure. Tests for the pH of each soil layer were made in the field by using a soil teskit. Observations

[1] Associate Soil Scientist, Research Assistant in Agricultural Engineering, and Associate Chemist, respectively, Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P. R. The writers wish to express their appreciation to Dr. R. M. Smith, formerly Supervisor of the Cooperative Bureau of Plant Industry, Soils, and Agricultural Engineering—Soil Conservation Service Research Project, now Director of the Blackland Experiment Station, Texas; and to Dr. J. A. Bonnet, Head of the Department of Soils of this Station, for their help in describing the soil profiles. Mr. S. Silva cooperated in taking the soil cores and in the physical measurements conducted at the laboratory. Appreciation is also expressed to O. L. Heyn and R. McConnie, of the Eastern Sugar Associates, for their cooperation in selecting the fields, and providing all labor and transportation when required.

were made also on root development throughout the profile. Samples were taken from each profile for chemical analysis in the laboratory.

Undisturbed soil cores were taken from several places to a depth of 72 inches by using a Kelley soil sampling machine (2).[2] Permeability measurements were made in these cores by recording the rate at which water moved through a column of saturated soil at a known head. In this measurement special equipment was used as described by Smith, Furhiman, and Silva (11). Quick drainage was determined by taking the saturated core to a Buchner funnel, setting up a 60-cm. tension, and measuring the water drained out at the end of 15 minutes. The water removed and retained at pF 1.78 was measured by bringing the soil cores to equilibrium with a 60-cm. tension and determining the variation in weight of the core. Water remaining at pF 2.7 and pF 4.2 was determined by submitting saturated soil samples to pressures of 1/2 and 15 atmospheres, respectively. The maximum saturation was calculated from the above data.

The soil core was finally dried in the oven at 110°C. As the samples used had a definite known volume, the bulk density of the soil was calculated by dividing the net dry weight of soil by its original volume. The pore space was then calculated by assuming a specific gravity of 2.65 which can be used advantageously for Puerto Rican soils (4).

The pH was determined electrometrically by means of a Macbeth pH meter. Conductivity measurements were made by using a standard solubridge. Total nitrogen was determined by the standard Kjeldhal method and the organic matter by the simple colorimetric Schollenberger technique. The exchange capacity was determined by the ammonium acetate method (10).

Infiltration tests were run in the field by using the buffer compartment method as outlined by Nelson and Muckenhirn (8). The procedure is briefly as follows:

Three concentric iron rings, each 5 inches in height, and 9, 18 and 27 inches in diameter, are driven into the ground 2 or 3-inch surface. The soil inside the two outside rings is kept saturated with water while the test is running. The infiltration test is run in the soil within the inner 9-inch ring, over which hangs a calibrated 2,000 ml. burette, the water reservoir. A volume of 1,043 ml. in this burette is equivalent approximately to one inch of water added to the 9-inch soil core. A pinchcock serves as a valve at the rubber hose that connects the tip of this burette to a small glass tube. The burette is filled with water to the 2,000 ml. mark and stoppered. The stopcock is opened and the starting time is recorded. Water infiltrates rapidly at first, into the soil, until the thin film of water that collects on the top soil touches the end of the small tube. This film serves as a regulator for the water to run from the burette as fast as the soil requires it. The time is recorded every time the burette is emptied to the zero mark. At this time the pinchcock is closed rapidly and the burette is refilled with water. The outfit is kept covered with a canvas.

[2] Numerals in parentheses refer to Literature Cited, p. 178.

The tests were run for eight consecutive hours. The amount of water used every hour was recorded. Each test was run in quadruplicate.

Morphological Characteristics of the Soils

A soil profile was studied in a pasture field of about 10 acres, at Colonia Preston, near road 28, (Juncos-Naguabo) Km. 12 H. 9. The soil was previously mapped in the Soil Survey of Puerto Rico (9) as Vía silty clay, but field examinations indicated that it approached more a Caguas silt loam. The soil was in native pasture, mostly carpet grass mixed with some native legumes and many weeds. The root development was rather weak all the way down, thinning out considerably with depth, being practically none below the 16-inch layer. The slope of the field ranged from about 4 to 10 percent.

A soil profile examined on September 26, 1950 was as follows:

0–7″	Light grayish-brown silt loam with some admixture of yellowish subsoil. Many large, dark concretions, some ½″in diameter, mostly about ⅛″. Not definite and rather fine granular structure. pH 6.6.
7–16″	Highly mottled, predominantly yellow clay. Well-developed fragmental-blocky structure. pH 6.0. Transition layer.
16–26″	Highly mottled clay, gray color predominant. Fragmental-blocky structure coarser than above. Cut like putty. Concretions in the upper 16–22″ section. pH 5.0.
26–30″ +	Gray, mottled brown and reddish-brown silty clay. Material resembling colloidal films along the cleavage planes. Prismatic structure, coarse, with tendency to vertical cleavage. pH 5.0.

On September 26, 1950 another profile was studied in a field at Colonia Sabana, road Las Piedras to San Lorenzo, Km. 17 H. 7. The sod had been recently turned under and the soil was being prepared for sugarcane planting. The soil was mapped as Las Piedras loam. It is derived from granite and occurs in gently rolling or undulating areas. The soil was covered with unimproved native pasture plants, but the root development was better than that observed in the profile previously described.

The profile examined was as follows:

0–7″	Light gray-brown loam or silt loam. Weak, crumb structure. Friable. pH 5.7.
7–19″	Highly varied color, but not true mottling, probably inherited from the parent material. Red, reddish-brown, and yellow clay loam. Blocky structure. pH 5.2.

19–26″	More rock color, loses reddish color. More sand, less clay. Some black streaks. pH 5.4. A transition zone to parent material.
26–50″ +	Fractures inherited from rock. Granular, light-yellow fine sand with block concretionary material. pH 6.4.

On October 26, 1950 a profile of Vía silty clay was examined at Colonia Buena Vista, on the outskirsts of Gurabo bordering the road to Trujillo Alto. The slope of the field was about 2 or 3 percent. The vegetation consisted mostly of sourgrass (Paspalum conjugatum) and weeds of the Calopogonium, Sesbania, Cyperus, Mimosa, and Eurena genera. All roots were concentrated above the gravel layer.

0–8″	Very dark gray to dark grayish-brown silty clay containing some gravel. Fragmental-blocky structure, medium size. pH 6.2.
8–11″	Transition zone.
11–21″	Gravelly clay, more gravel in the lower part. Some brown, gray, and yellowish mottling, the last predominating. Blocky structure. pH 7.0.
21–30″	Gravel layer. Very weak structure.
30–65″	Clay loam. Yellowish-brown with dark gray. Prismatic structure. From 32–38″ is more gravelly than below. From 40–48″ more uniform with some almost black mottlings. From 48–60″ contains more sand.
65–72″ +	Second gravel layer.

A profile of Mabí silty clay was studied on November 8, 1950, at the Buonomo farm near the Gurabo-Caguas road. The slope of the field was about 3 percent. The vegetation consisted mostly of carpet and Bermuda grasses.

0–10″	Dark reddish-brown silty clay with some small stone fragments. Fairly well-developed medium fine fragmental-blocky structure.
10–20″	Dark reddish-brown, silty clay with very little mottling. Fairly dense, distinct fragmental-blocky structure.
20–30″	Structure coarser than above, became more massive with depth.
30–38″	Sandy clay layer, rather loose.
36–48″	Clay layer, tight.
48–60″ +	Very dense clay layer.

A profile of Mabí clay loam, poorly drained phase, was examined near the road from Las Torres to Las Piedras. The slope of the field was about 2 percent. The field had a dense stand of malojillo.

0–9″ Dark-brown mottled clay loam with dark iron and manganese concretions.

9–21″ Sandy clay loam. Mottled from almost white to almost black, predominantly white, pale color. Also grayish brown. Lower part began to change to reddish yellow. Structure almost massive except for old root holes.

TABLE 1.—*Mean pH, organic matter, nitrogen, and exchange capacity of some selected soils from east-central Puerto Rico*

Soil type	Location	Depth	pH	Organic matter	Nitrogen	Total exchange capacity
		Inches		*Percent*	*Percent*	*M.e./100 gm. dry soil*
Caguas silt loam	Colonia Preston	0–7	6.6	1.0	0.15	9.5
		7–16	6.0	(1)	.02	10.0
		16–26	4.9	(1)	.05	11.4
		26+	5.0	(1)	(1)	12.5
Las Piedras loam	Colonia Sabana	0–7	4.8	.5	.11	10.6
		7–19	5.8	.3	.03	17.1
		19–26	5.5	(1)	.01	25.1
		26+	6.3	(1)	.01	21.6
Vía silty clay	Colonia Buena Vista	0–8	6.4	2.0	.15	18.7
		11–21	6.8	.2	.06	24.4
		21–30	7.0	(1)	.04	22.9
		30–50	7.0	(1)	.03	22.2
		50+	6.9	(1)	.03	16.9

[1] Trace.

21–36″ Sandy clay loam. Highly mottled white, yellowish brown, and black. Structure almost massive. May be tightest layer of profile.

36″ + Water-bearing sandy layer.

CHEMICAL PROPERTIES

The results of the chemical analyses of three profiles sampled in east-central Puerto Rico are shown in table 1. The pH values for Caguas silt loam indicate considerable variability throughout the profile. They range from very strongly acid in the lower two layers to slightly acid or nearly neutral in the surface layer. On the other hand, in the profile of Las Piedras

loam the surface soil is very strongly acid while the acidity is only slight after the 2-foot layer. The least fluctuations are observed in the profile of Vía silty clay.

The soils of east-central Puerto Rico are very low in organic matter. The surface layer of Las Piedras loam has the lowest content, only 0.5 percent of organic matter, and Vía silty clay the highest, but only 2.0 percent. The decrease in organic matter from the surface layer to the lower layers in the profile is highly significant. In the Vía silty clay the organic-matter content at the second horizon of the profile is only one-tenth that of the upper 8-inch layer. The nitrogen content of the plow layer in all three profiles is medium low. When going downward in the profile the variations in nitrogen content follow the same pattern as the organic-matter content, decreasing markedly to a very low limit.

The alluvial Vía soil has a total exchange capacity that can be considered moderately high, and high just beneath the plow layer. The values for Caguas silt loam range from moderage to moderately low. In the Las Piedras profile the changes are more radical ranging from moderately low in the upper layers, to moderately high in the lower subsoil.

Physical Properties

Table 2 gives the results of permeability tests and other soil-moisture studies conducted on a number of undisturbed soil cores collected in the area. The permeability measurements made on undisturbed cores of a Caguas silt loam gave very slow and slow rates of percolation for all layers after the upper two feet. The 16–22-inch layer had a moderate rate of percolation of 3.90 inches per hour and the permeability of the surface layer was only 1.31 inches per hour. The "quick-drainage" values follow more or less the same pattern as did permeability measurements. Values for maximum saturation do not differ much for the various layers sampled. Permanent wilting percentage values (water remaining at pF 4.2) are high, ranging from 23.9 percent at the plow layer to 46.2 percent towards the bottom of the 6-ft. profile.

If the available water for crops is regarded as the difference between water remaining in the soil when tensions equivalent to pF 1.78 are applied and that remaining when permanent wilting occurs (pF 4.2) the upper 3 feet of Caguas silt loam will be able to hold about 6.46 acre-inches of water available for crops. A soil with a capacity to store that quantity of available water in the crop root zone can be rated as one having a moderately high water-supplying power.

The permeability measurements on cores of Vía silty clay indicate a rather rapid rate of percolation in the upper 15 inches with a sharp decrease when hitting the 18–24-inch layer. Permanent wilting percentage values range

from 16.2 to 26.2 percent, considerably lower than in the first profile. Similar calculations as those made previously in regard to the available water supply indicate a maximum value of 7.76 acre-inches in the crop root zone (upper 38 inches). By comparison with standards which have been es-

TABLE 2.—*Permeability and other soil-moisture data on soil cores from east-central Puerto Rico*

Soil type	Depth	Permeability	Water drained at 60 cms. in 15 minutes	Maximum saturation	Water remaining at pF—			Available water (water at pF 1.78–water at pF 4.2)
					1.78	2.7	4.2	
	Inches	*Inches/hour*	*Percent*	*Percent-water*	*Percent*	*Percent*	*Percent*	*Percent*
Caguas silt loam	0–6	1.31	2.5	51.7	46.4	37.0	23.9	22.5
	7–14	1.44	1.9	46.6	42.3	39.9	26.8	15.5
	16–22	3.90	2.0	54.1	50.1	43.3	32.8	17.3
	23–30	.19	1.0	54.8	51.6	46.9	34.9	16.7
	32–38	.22	.9	56.1	54.1	51.0	37.6	16.5
	40–46	—	.8	55.5	53.8	51.0	35.2	18.6
	46–52	.02	.8	54.1	52.6	49.6	34.9	17.7
	53–60	.004	.7	53.1	51.3	50.5	34.9	16.4
	66–72	.001	.3	49.7	48.7	50.5	46.2	2.5
Vía silty clay	0–7	4.80	2.8	52.1	45.6	34.5	19.5	26.1
	8–15	2.10	1.1	47.8	45.1	42.2	25.0	20.1
	18–24	.74	2.1	47.3	42.8	43.2	26.2	16.6
	24–31	.86	3.2	44.3	38.1	28.7	16.2	21.9
	32–38	.86	1.6	45.4	40.2	35.9	22.5	17.7
	40–48	3.25	1.5	45.7	42.0	43.3	24.3	17.7
	48–55	1.20	2.1	44.1	40.4	42.7	25.0	15.4
	55–62	.60	1.9	45.9	38.4	35.5	20.9	17.5
Mabí silty clay	0–8	27.5	3.5	43.1	35.7	36.6	25.4	10.3
	8–16	2.70	2.9	50.5	44.0	42.2	28.4	15.6
	20–26	.028	.6	47.7	46.0	44.0	30.4	15.6
Mabí clay loam	0–9	7.61	3.0	45.7	39.4	35.0	17.4	22.0
	9–14	8.82	3.9	41.0	31.9	27.7	14.3	17.6
	14–21	1.80	2.6	40.0	31.4	27.8	12.7	18.7
	21–28	2.93	1.6	39.1	34.8	32.8	17.1	17.7
	28–36	1.75	1.5	40.0	35.8	19.5	11.4	24.4
	36–42	8.64	3.5	37.4	26.1	10.4	7.0	19.1

tablished (12) this Vía silty clay profile would rank as having a moderately high available water-holding capacity.

The very rapid percolation rate measured in the upper 8-inch layer of Mabí silty clay probably results from the many channels and root holes

observed while sampling. It falls sharply to moderately rapid in the next layer and to very slow when the 20–26-inch layer is reached. Permanent wilting occurs when the soil still retains a relatively large amount of water, thus reducing its available water supply. The measurements made indicate a reliable storage reservoir of 3.65 inches of water in the upper 2 feet of the

TABLE 3.—*Bulk density, pore space, and air capacity of selected soil profiles from east-central Puerto Rico*

Soil type	Depth	Bulk density	Total porosity	Air porosity (total porosity-water retained at pF 1.78)
	Inches	*Gm./c.c.*	*Percent*	*Percent*
Caguas silt loam	0–6	1.26	52.4	6.0
	7–14	1.45	45.3	3.0
	16–22	1.19	55.1	5.0
	23–30	1.21	54.8	3.2
	32–38	1.20	56.1	2.0
	40–46	1.23	55.5	1.7
	46–52	1.30	54.1	1.5
	53–60	1.36	53.1	1.8
	66–72	1.43	49.7	1.0
Vía silty clay	0–7	1.24	53.2	8.6
	8–15	1.39	47.5	2.4
	18–24	1.44	45.7	2.9
	24–31	1.45	45.3	7.2
	32–38	1.48	44.1	3.9
	40–48	1.49	44.5	2.5
	48–55	1.50	43.4	3.0
	55–62	1.53	42.3	3.9
Mabí silty clay	0–8	1.27	52.1	16.4
	8–16	1.31	50.6	6.6
	20–26	1.39	47.5	1.5
Mabí clay loam	0–9	1.43	46.0	6.6
	9–14	1.49	43.8	11.9
	14–21	1.53	42.3	10.9
	21–28	1.57	40.1	5.3
	28–36	1.56	41.1	5.3
	36–42	1.46	44.9	18.8

profile. Assuming the same storage capacity for the next 10 inches, the crop root zone will have 5.21 inches of water available for crops. Similar calculations for the Mabí clay loam profiles show that this soil can store in readily available form approximately 7.36 acre-inches of water in the upper 3 feet where the bulk of the roots of crops plants are generally found.

Table 3 presents data on bulk density, total porosity, and air porosity of four profiles sampled in east-central Puerto Rico. Bulk-density values for the uppermost layers are around 1.25 gm./c.c. for all the profiles, except that of Mabí clay loam where it is 1.43 gm./c.c. As a rule bulk density increases with depth. In general, total-porosity values are larger where bulk-density values are smaller. They range from approximately 40 to 56 percent by volume. The soil solids occupy the remaining soil volume. By far the largest proportion of pores is filled with water at pF 1.78. The air porosity is in inverse relationship to the water porosity.

TABLE 4.—*Mean infiltration capacity of selected soils from east-central Puerto Rico*

Soil type	Location	Infiltration rate in inches of water per hour given—							
		1	2	3	4	5	6	7	8
Caguas silt loam	Colonia Preston	2.21	1.60	1.55	1.60	1.73	1.70	1.00	0.46
Vía silty clay	Colonia Buena Vista	2.06	.60	.67	.75	.77	.92	1.16	1.06
Vía clay loam	Colonia Río Grande	1.29	.17	.17	.16	.13	.17	.23	.19
Vía clay loam	Colonia Miraflores	6.63	4.12	4.08	2.95	2.23	2.15	1.59	1.43
Las Piedras loam	Colonia Sabana	1.70	.73	.69	.76	1.29	1.41	1.49	1.36
Las Piedras loam	Colonia Sabana	3.13	1.83	1.92	1.74	2.14	2.01	2.04	2.09
Las Piedras clay loam	Colonia Doctores	3.81	1.36	1.75	1.65	1.60	1.68	2.02	1.82
Las Piedras clay loam	Colonia Doctores	1.27	1.35	1.11	.97	.75	.69	.99	.29
Mabí clay	Colonia Río Grande	20.19	10.41	4.36	3.56	3.34	2.41	1.64	1.89
Mabí clay	Colonia Preston	.57	.26	.15	.23	.28	.43	.42	.19

INFILTRATION CAPACITY

The Caguas soil had a slow infiltration rate after it had been thoroughly soaked. The rate of infiltration of the Vía soils at the eighth-hour ranges from slow to moderate. Considerable variation can be observed in the Las Piedras soils which range from 0.29 inches per hour, a slow rate, to 2.09 inches per hour, a moderately rapid rate. The Mabí soils range from slow to moderate in their infiltration capacity at the eighth-hour run. In general, the minimum infiltration capacity of the soils of the east-central area is rather slow. (See table 4.)

DISCUSSION

The morphological studies point to the presence of tight subsoil layers at variable depths beneath the surface soil in large areas of east-central Puerto Rico. It is very fortunate that many other areas in the same section do not

have this undesirable feature. The presence of this compact subsoil considerably reduces the permeability of the profile and thus is a direct cause of imperfect and even poor drainage in many lowlands of the region. Ordinary plowing operations considerably increase the rate of infiltration of water through the upper profile layers. However, subsurface tillage practices can cause still a larger increase (7). In an area of heavy rainfall, like the one under consideration, where large volumes of water must be disposed of quickly so as not to impair crop growth, the loosening of the tight subsoil layers, where present, with the consequent increase in water infiltration is of fundamental importance. Improvement in the internal drainage of many soils of this area will probably result in more efficient land utilization, reduced farm expenses, and more effective soil and moisture conservation.

Field observations indicate that crop plants fail to develop extensive and deep root systems when grown in the compact soils of the area. The possibility of developing larger root systems through shattering and increasing the fertility level of subsoils deserves careful consideration (6). Liming is not a generalized practice in east-central Puerto Rico. However, the extreme acidity of many of the soils of the area must be properly corrected in order to obtain better yields and to maintain soil productivity over a longer period of time. Sugarcane, the crop which is grown on a large commercial basis in the region, is generally fertilized quite heavily. In order to reduce leaching loses to a minimum, careful attention must be given to the moderate exchange capacity of the main soils of the region, so as not to apply nutrients much in excess of what the soil colloids can hold at a given time.

Efforts should be made to maintain a reasonable level of organic matter in the soils of the area, though no definite figure can be given. In sugarcane fields the problem is not too difficult considering the large amount of trash, roots, and other crop residues present. The increase in the level of organic matter through the proper handling of trash has proved very beneficial for crop yields through its effect on soil properties (3, 5). Moreover, mulching with trash can be very beneficial to the hilly soils of the area from the standpoint of soil and water conservation. Experience with four crops of sugarcane (1944–1948) grown in a lateritic soil with a 40-percent slope in western Puerto Rico indicates that unmulched plots lose about 11 times as much soil as the mulched ones (1). Efforts to build up and maintain a very high level of organic matter would be rather expensive, and they may fail to produce the expected benefits. The objective should be to maintain the lowest level compatible with adequate energy release for microorganisms, adequate nutrient availability, and profitable crop yields.

The soil-moisture studies indicate that the soils of the area generally have a moderately high capacity to store available water for crop growth. Field observations over a long period of time have shown that the soils of the

area are generally able to supply sufficient moisture for crop growth throughout the year, except during periods of very prolonged drought. The laboratory results have confirmed this fact on a basis of the capacity of the soil to store water at tensions which are low enough for plants to use it efficiently.

It might be helpful to have some more additional fertility and soil-moisture measurements covering a larger number of samples. However, the results so far available provide important reference points for estimates of what to expect from most of the soils of the area.

Summary

This report presents the results of a preliminary soil reconnaissance in east-central Puerto Rico. It contains soil-profile observations made on several deep pits dug for the purpose. It also includes the results of various infiltration tests conducted in the major soil types of the area. The laboratory data reported include organic matter, pH, nitrogen, and total exchange capacity, and also the following measurements conducted on undisturbed soil cores dug with a Kelley (Utah) soil sampling machine: Permeability, quick drainage, water retained at pF 1.78, maximum saturation, and bulk density. Additional data are presented on water retained at pF 2.7 and pF 4.2, available water, total porosity, and air porosity.

The soils of east-central Puerto Rico are rather deep, medium- or heavy-textured, acid, and of medium to low fertility. They are not generally well supplied with organic matter and nitrogen. In many cases they have compact, tight subsoil layers near the surface which considerably reduce the permeability of the profile and induce poor drainage. Laboratory soil-moisture studies confirmed field observations indicating that the majority of the soils of this region have a moderately high capacity to store water available for crop growth.

Resumen

En este trabajo se informan los resultados de un reconocimiento preliminar de los suelos de la zona este-central de Puerto Rico. Incluye el informe observaciones hechas en varias trincheras preparadas para el estudio. Incluye, además, los resultados de varias pruebas de infiltración que se hicieron en los tipos de suelos más importantes del área. Se presentan datos de laboratorio, tales como determinaciones de materia orgánica, pH, nitrógeno y capacidad total de intercambio. También se presentan datos sobre las siguientes determinaciones hechas en columnas de suelo en su estado natural que se obtuvieron con una máquina especial del tipo desarrollado por Kelly en Utah: permeabilidad, agua removida en 15 minutos a una tensión de 60 centímetros, agua retenida a pF 1.78, saturación máxima

y peso por volumen. Se presenta también información sobre el agua retenida a pF 2.7 y a pF 4.2, el agua aprovechable, la porosidad total y la proporción de poros gruesos.

Los suelos de la región este-central de Puerto Rico son bastante profundos, de textura mediana o pesada, ácidos y de una fertilidad baja o mediana. Generalmente, no están bien provistos de materia orgánica y nitrógeno. En muchos casos, se encuentran relativamente cerca de la superficie subsuelos compactos y pesados que reducen considerablemente la permeabilidad del perfil, restringiendo el desagüe. Los estudios de laboratorio han confirmado las observaciones de campo de que la mayoría de los suelos de esta zona tienen una capacidad moderadamente alta para retener el agua a tensiones lo suficientemente bajas, de modo que las plantas la puedan utilizar eficientemente.

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TILLAGE TESTS

I. EFFECT OF SUBSOILING AND MOLE DRAINAGE UPON THE MINIMUM INFILTRATION CAPACITY OF A HEAVY CLAYPAN SOIL OF THE TROPICS

M. B. Martínez and M. A. Lugo López[1]

Introduction

There are probably more than 250,000 acres of cultivated land in Puerto Rico on which internal drainage could be improved considerably by the use of better tillage practices. This area includes a great variety of soil types of the inner and river flood plains, coastal lowlands, and the terraces and alluvial fans. Large areas of soils of the Caguas, Candelero, Sabana Seca, Mabí, Moca, Coloso, Vega Baja, Yabucoa, Josefa, Maunabo, Las Piedras, Camaguey, Santa Clara, Lares, and other series have tight subsoil layers which interfere with root penetration, water movement, and aeration (6).[2] Unless these areas are properly tilled, the roots of plants growing on them are restricted to small volumes of soil, thus reducing the available nutrients and moisture. Yields are considerably lower in these places than in the better drained sections. A regular feature of these areas, which are mostly devoted to sugarcane cultivation, is the large number of ditches required to dispose of run-off waters (3).

In other regions with similar problems attempts have been made to improve the situation by using deep-tillage practices, drainage, and subsoil fertilization (7). Subsoiling has been a regular practice in some Puerto Rican plantations of moderately heavy soils but in others, with claypan layers underneath the surface, the practice is virtually unknown (4). No experimental measurements have been performed properly to evaluate the effect of these practices upon soil tilth or crop yields. Mole-drainage systems have been installed in the past to a very limited extent, but the practice never became generalized and disappeared without apparent reason.

Following a preliminary survey of many farm lands a plan was outlined to evaluate tillage practices currently used and to test experimentally others that might prove more practical. The improvement of soils by techniques that promote better internal drainage and aeration may lead to reduced farm expenses, more efficient land utilization, and increased crop yields.

[1] Research Assistant in Agricultural Engineering and Associate Soil Scientist, respectively, Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P. R.

[2] Numerals in parentheses refer to Literature Cited. p. 185.

Soil Characteristics

The area selected for establishing the first tillage test is located in Colonia Preston, a large sugar estate of east-central Puerto Rico. The experimental field was located near road 28, km. 12 H. 9. Various pits were dug at different parts of a 10-acre field to study the morphological characteristics of the soil. In addition, soil cores for laboratory studies were obtained with a Kelley (Utah) soil-sampling machine (2). The soil was previously mapped in the Soil Survey of Puerto Rico (6), as Vía silty clay, but field examinations indicated that it approached more a Caguas silt loam.

The soil was in native pasture, mostly carpet grass mixed with some native legumes and many weeds. The root development was rather weak all the way down, thinning out considerably with depth, being practically none below the 16-in layer. A soil profile examined on September 26, 1950, was as follows:

0–7″	Light grayish-brown silt loam with some admixture of yellowish subsoil. Many large, dark concretions, some ½″ in diameter, mostly about ⅛″. Indefinite and rather fine granular structure. pH 6.6.
7–16″	Highly mottled, predominantly yellow clay. Well-developed fragmental-blocky structure. pH 6.0. Transition layer.
16–26″	Highly mottled, gray color predominant, clay. Fragmental-blocky structure coarser than above. Cut like putty. Concretions in the upper 16–22″ section. pH 5.3 in gray material, 4.7 in brown material.
26–50″ +	Gray, mottled brown and reddish-brown silty clay. Material that looked like colloidal films along the cleavage planes. Prismatic structure, coarse, with tendency to vertical cleavage. pH 5.0.

The slope of the field ranged from about 4 to 10 percent. The tight layer appeared closer to the surface in approaching the higher parts of the field. Permeability measurements made on undisturbed cores gave slow rates of only 0.19 inches of water per hour for the 23- to 26-inch layer indicating that this was a very tight layer. The layer above it had a moderate rate of percolation of 3.90 inches of water per hour and the permeability of the surface layer was only 1.31. The total exchange capacity ranged from 9.5 to 12.5 m.e. per 100 gm. of dry soil, the higher values corresponding to the deeper layers.

Experimental Lay-out and Procedure

An incomplete block design, the triple lattice, was used for the experimental lay-out (1). This type of design has proved to be very precise, especially when using a large number of treatments. The plots were rather

large, 200 feet times 20 feet wide, to facilitate the operation of heavy equipment.

Land preparation was started on October 11, 1950, by passing a disk harrow twice to cut the sod. From November 8–15 the land was plowed and harrowed three times with disks to a depth of about 12 inches. Furrows were made every 5 feet, four to each plot. Although the field was ready for treatments and planting, these operations were deferred to a later date because of unusually heavy rains. The soil was too wet for several weeks. On January 10, 1951, after a few days of intense sunlight, a fourth disking was performed and the furrows were prepared over again. Surface drainage was provided by ditches every 25 feet at right angles to the furrows and leading to larger drainage ditches dug to follow the topography of the land. From January 17 to 24, 1951, the treatment differentials were established

TABLE 1.—*Treatment differentials established on the experimental field on a heavy claypan soil in east-central Puerto Rico, showing other treatments occurring in the same group according to design used*

Treatment No.	Description	Other treatments in the same group[1]
1	Check	2, 3, 4, 5, 7, 9
2	Subsoiling	1, 3, 5, 6, 7, 8
3	Subsoiling + fertilizer on subsoil	1, 2, 4, 6, 8, 9
4	Subsoiling + lime on subsoil	1, 3, 5, 6, 7, 8
5	Subsoiling + fertilizer and lime on subsoil	1, 2, 4, 6, 8, 9
6	Subsoiling and mole drainage	2, 3, 4, 5, 7, 9
7	Subsoiling and mole drainage + fertilizer on subsoil	1, 2, 4, 6, 8, 9
8	Subsoiling and mole drainage + lime on subsoil	2, 3, 4, 5, 7, 9
9	Subsoiling and mole drainage + lime and fertilizer on subsoil	1, 3, 5, 6, 7, 8

[1] Refer to table 3 for the grouping system.

as described in table 1. In this table also are shown those treatments which occurred in same group with each respective treatment.

For these treatments an International TD-9 Diesel Crawler Tractor, wide-tread model (60-inch width center to center of tracks), 16-inch track shoes; heavy-duty equalizer spring; with extended tracks and track frame, was used. A hydraulic system consisting of pump, valve, tank, and hoses, to operate "International-Universal" tool bar (basic) was directly connected to the tractor. The tool bar floated and was hinged for horizontal movements. On this bar was mounted a heavy-duty standard with subsoil point with a removable mole attached. A fertilizer attachment for subsoil was mounted so as to be motivated by the tractor's power take-off which stopped automatically when the tool bar was in the raised position for turning and transporting the tractor; it started automatically when the

tool bar was lowered. The standard was graduated so that the subsoil point would penetrate 30 inches.

In treatments 3, 5, 7, and 9 a 13–3–12 fertilizer was applied to the subsoil at the rate of 1,000 pounds to the acre. In treatments 4, 5, 8, and 9 an application of limestone at the rate of 1,000 pounds to the acre, as indicated by lime-requirement tests, was made at the subsoil breakpoint. Each treatment was replicated nine times. Cane variety POJ 2878, standard for the region, was planted from February 7–21. Two applications of fertilizer were made later to a total of 2,000 pounds to the acre. The first and second surface applications of fertilizer were at only half the rate for plots that received fertilizer at the subsoil as for those that had not previously received this subsoil treatment. Other agronomic practices were conducted as was customary for the region.

During the period from September 17 to October 10, 1951, 8 months after establishing the treatment differentials, infiltration tests were conducted on each plot. Four tests were also conducted on an adjoining plot devoted to pasture which had not been plowed for many years. The buffer-compartment technique as outlined by Nelson and Muckenhirn was used (5). The procedure is as follows:

> Three concentric iron rings, each 5 inches in height, and 9, 18, and 27 inches, respectively, in diameter, are driven into the ground 2 or 3 inch surface. The soil inside the two outside rings is kept saturated with water while the test is running. The infiltration test is run in the soil within the inner 9 inch ring, over which hangs a calibrated 2,000 ml. burette, the water reservoir. A volume of 1,043 ml. in this burette is equivalent approximately to one inch of water added to the 9-inch soil core. A pinchcock serves as a valve at the rubber hose that connects the tip of this burette to a small glass tube. The burette is filled with water to the 2,000 ml. mark and is stoppered. The stopcock is opened and the starting time recorded. Water infiltrates rapidly at first, into the soil, until the thin film of water that collects on the top soil touches the end of the small tube. This film serves as a regulator for the water to run from the burette as fast as the soil requires it. The time is recorded every time the burette is emptied to the zero mark. At this time the pinchcock is closed rapidly and the burette is refilled with water. The outfit is kept covered with a canvas.

The tests were run for eight consecutive hours, the quantity of water used every hour being recorded. The results of the eighth-hour run were analyzed statistically according to the design used.

Results and Discussion

The results of the statistical study of the infiltration rate obtained for the eighth hour are presented in tables 2 and 3. Table 2 shows the analysis of the total sum of squared deviations of the infiltration data. The values for B and E are 198.9 and 126.1 respectively. These values were used in correcting the mean infiltration rates obtained in the field. Table 3 gives the corrected mean infiltration rate of water at the eighth hour for each tillage

treatment. The form of presentation facilitates the comparison between treatments to detect their significance.

The mean infiltration rates of all plots where either subsoiling or subsoiling and mole drainage were practiced are significantly higher than that of the check plots. The mean differences between them and the check are significant at the 1-percent level in all cases, excepting differences between

TABLE 2.—*Analysis of total sum of squared deviations of infiltration-rate data from the experimental field in east-central Puerto Rico*

Source of variation	Degrees of freedom	Sum of squares	Mean square
Replications	8	3,681.46	
Component a	12	2,386.40	198.9 = *B*
Component b	6	519.10	
Blocks (eliminating treatments)	18	2,905.50	
Treatments (eliminating blocks)	8	3,015.28	126.1 = *E*
Error (intrablocks)	46	5,800.32	
	80	15,402.56	

TABLE 3.—*Corrected mean infiltration rate of water at the eighth hour in plots undergoing different tillage treatments*

Treatment	1(a)[1]	2(b)	3(c)
Inches of water per hour	5.6	26.7	21.5
Treatment	4(c)	5(a)	6(b)
Inches of water per hour	18.9	23.1	22.4
Treatment	7(b)	8(c)	9(a)
Inches of water per hour	25.3	19.6	23.1

[1] Respective letters in parenthesis refer to the *Z* grouping in the statistical analyses. For other treatments within the same group see table 1.

L.S.D. for treatments within the same group:	
at the 5-percent level	11.18
at the 1-percent level	14.91
L.S.D. for treatments not within the same group:	
at the 5-percent level	11.77
at the 1-percent level	15.70

treatments 4, 8, and 1, which are significant only at the 5-percent level. No significant differences could be observed between any other treatments.

From the standpoint of water infiltration subsoiling is a very efiective practice in areas of heavy claypan soils. Soils treated in this way, even when saturated, can readily absorb four or five times as much water as soils the claypan layers of which remain undisturbed by ordinary tillage practices. The following tabulation shows the infiltration rate of water at four sites in

a pasture plot adjoining the experimental field which had not been disturbed by plowing operations for many years.

Treatment	*Eighth-hour infiltration rate Inches per hour*
Undisturbed	0.70
Do.	1.10
Do.	.02
Do.	.03
Plowed and harrowed 4 times	5.60

For establishing comparisons readily the mean rate of infiltration of the nine control plots is also given. The mean rate at the eighth hour of all four undisturbed sites is only 0.5 inch of water per hour. By ordinary plowing and harrowing only, the infiltration capacity of this soil was increased tenfold. These facts show the effectiveness of the ordinary land-preparation operations.

A rate of infiltration of more than 5 inches per hour is very rapid and should indicate no drainage problems. However, it must be remembered that areas of these soils usually occur in flat lands where large volumes of run-off waters coming from the adjoining hills and mountains must be disposed of quickly. Thus, even with rains of small intensities, large quantities of water collect on low fields which may be very harmful to growing crops unless internal drainage is very good. Subsoiling and subsoiling plus mole drainage assure a very rapid rate of infiltration.

The permeability measurements reported previously indicated a very slow rate of percolation of only 0.19 inches per hour for the tight subsoil layer. This suggests the possibility that most of the water entering the soil of the check plots through the immediate surface, moved laterally after reaching the tight layer, rather than downward in the profile. In the treated plots where the tight layer was disturbed by the subsoil standard, the water probably moved downwards through the disturbed tight layer, thus accounting for the excessively rapid rates of infiltration measured in these plots.

The period during which the various tillage practices will be effective remains yet to be determined. It will be interesting to find out whether the subsurface tillage will remain more effective with passage of time than surface tillage. The indirect effects of subsoil fertilization and liming, through better developed and more extensive root systems, may be measurable in the next few years.

Summary

Data are presented here on the minimum infiltration capacity of a heavy claypan soil under different tillage treatments. The experiment was laid out following a triple lattice design. The mean rate of infiltration at the

eighth hour of an undisturbed pasture plot was 0.5 inches per hour. The minimum infiltration capacity of the check plots which were plowed and harrowed four times was 5.6 inches per hour. This rapid rate of infiltration in the check plots suggests the possibility of lateral flow instead of downward movement of water in the plots where the tight claypan layer was disturbed either by subsoiling or by subsoiling and mole drainage. The plots that received the subsoiling and subsoiling and mole-drainage treat ments had significantly higher rates of infiltration than the control plots.

Resumen

Se presentan datos aquí sobre la capacidad de infiltración de un suelo con un "claypan" sometido a varios tratamientos durante las operaciones de la preparación del terreno. El experimento se estableció siguiendo un diseño de enrejillado triple. La velocidad promedio de la infiltración del agua a la octava hora en un lote dedicado a pasto, donde no se hicieron operaciones de preparación o cultivo, fué de 0.5 de pulgada por hora. La capacidad mínima de infiltración de las parcelas testigo, que se ararón y rastrillaron cuatro veces, fué de 5.6 pulgadas de agua por hora. Esta infiltración tan rápida en estas parcelas, se puede explicar, quizás, a base del movimiento lateral del agua en vez de vertical, como en el caso de las parcelas donde se pasó un arado de subsuelo para romper el "claypan" o en las que se estableció un sistema de desagüe subterráneo, además de pasar el arado de subsuelo. En las parcelas donde se pasó el arado de subsuelo y donde se instaló el sistema subterráneo de desagüe, se obtuvieron valores significativamente más altos, para la capacidad de infiltración, que en las parcelas testigo.

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